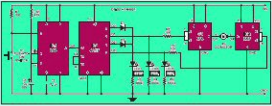
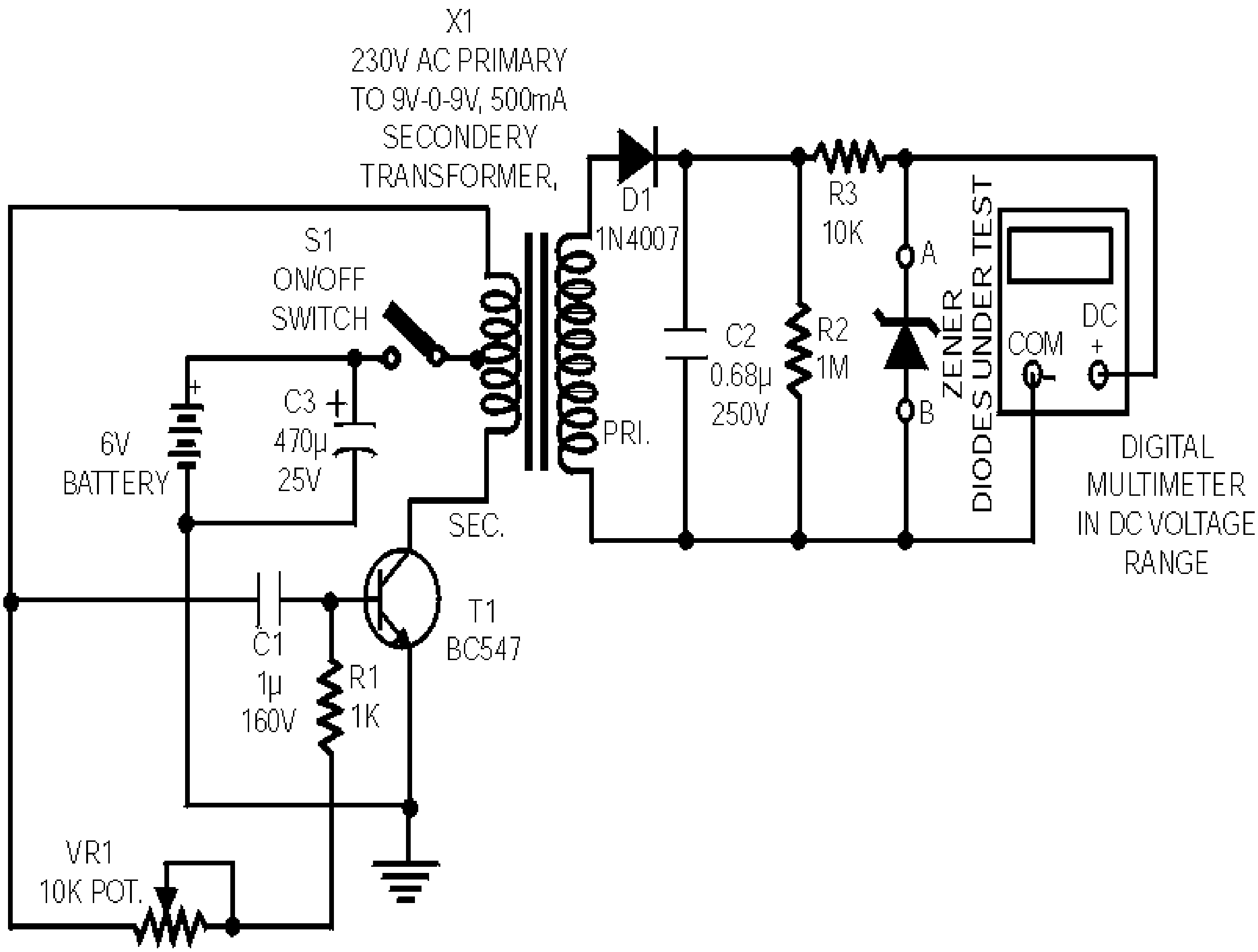
Electronics Hobby Circuits



No-2

Handy Zener Diode Tester



Here is a handy zener diode tester which tests zener diodes with breakdown voltages extending up to 120 volts. The main advantage of this circuit is that it works with a voltage as low as 6V DC and consumes less than 8 mA current. The circuit can be fitted in a 9V battery box. Two-third of the box may be used for four 1.5V batteries and the remaining one-third is sufficient for accommodating this circuit. In this circuit a commonly available transformer with 230V AC primary to 9-0-9V, 500mA secondary is used in reverse to achieve higher AC voltage across 230V AC terminals. Transistor T1 (BC547) is configured as an oscillator and driver to obtain required AC voltage across transformer's 230V AC terminals. This AC voltage is converted to DC by diode D1 and filter capacitor C2 and is used to test the zener diodes. R3 is used as a seri- es current limiting resistor. After assembling the circuit, check DC voltage across points A and B without connecting any zener diode. Now switch on S1. The DC voltage across A-B should vary from 10V to 120V by adjusting potmeter VR1 (10k). If every thing is all right, the circuit is ready for use. For testing a zener diode of unknown value, connect

it across points A and B with cathode towards A. Adjust potmeter VR1 so as to obtain the maximum DC voltage across A and B. Note down this zener value corresponding to DC voltage reading on the digital multimeter. When testing zener diode of value less than 3.3V, the meter shows less voltage instead of the actual zener value. However, correct reading is obtained for zener diodes of value above 5.8V with a tolerance of ± 10per cent. In case zener diode shorts, the multimeter shows 0 volts.

HOUSE SECURITY SYSTEM

MALAY BANERJEE

EFY SUNIL KUMAR TESTED

Here is a low-cost, invisible laser circuit to protect your house from thieves or trespassers. A laser pointer torch, which is easily available in the market, can be used to operate this device.

The block diagram of the unit shown in Fig. 1 depicts the overall arrangement for providing security to a house. A laser torch powered by 3V power-supply is used for generating a laser beam. A combination of plain mirrors M1 through M6 is used to direct the laser beam around the house to form a net. The laser beam is directed to finally fall on an LDR that forms part of the receiver unit as shown in Fig. 2. Any interruption of the beam by a thief/trespasser will result into energisation of the alarm. The 3V power-supply circuit is a conventional full-wave rectifier-filter circuit. Any alarm unit that operates on 230V AC can be connected at the output.

The receiver unit comprises two identical step-down transformers (X1 and X2), two 6V relays (RL1 and RL2), an LDR, a transistor, and a few other passive components. When switches S1 and S2 are activated, transformer X1, followed by a full-wave rectifier and smoothing capacitor C1, drives relay RL1 through the laser switch.

The laser beam should be aimed continuously on LDR. As long as the laser beam falls on LDR, transistor T1 remains forward biased and relay RL1 is thus in energised condition. When a person crosses the line of laser beam, relay RL1 turns off and transformer X2 gets energised to provide a parallel path across N/C contact and the pole of relay RL1. In this condition, the laser beam will have no effect on LDR and the alarm will continue to operate as long as switch S2 is on.

When the torch is switched on, the pointed laser beam is reflected from a definite point/place on the periphery of the house. Making use of a set of properly oriented mirrors one can form an invisible net of laser rays as shown in the block diagram. The final ray should fall on LDR of the circuit.

Note. LDR should be kept in a long pipe to protect it from other sources of light, and its total distance from the source may be kept limited to 500 metres. The total cost of the circuit, including the laser torch, is Rs 400 or less. ❑

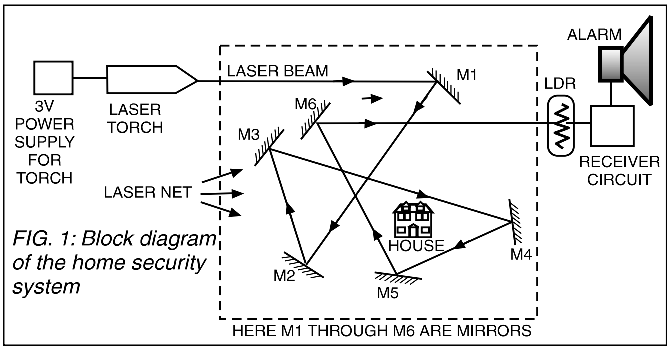


FIG. 1: Block diagram of the home security system

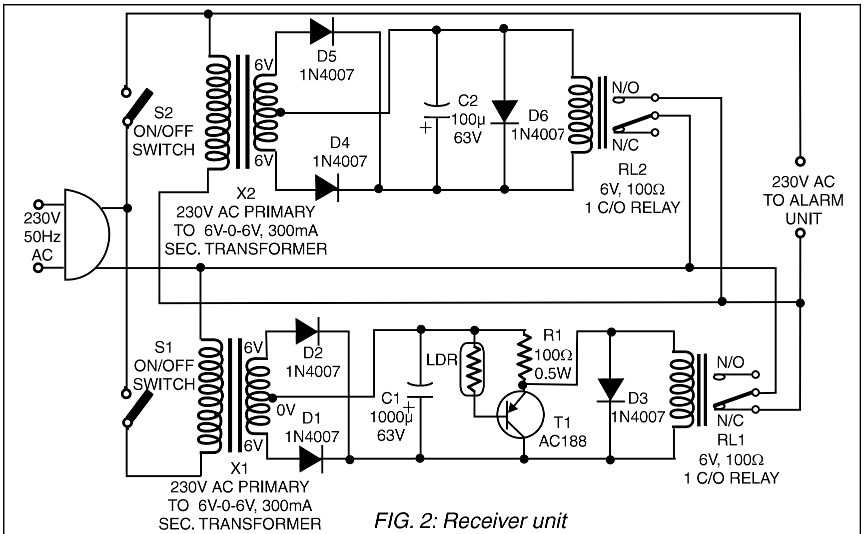


FIG. 2: Receiver unit

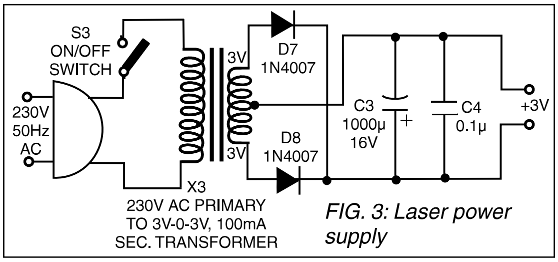
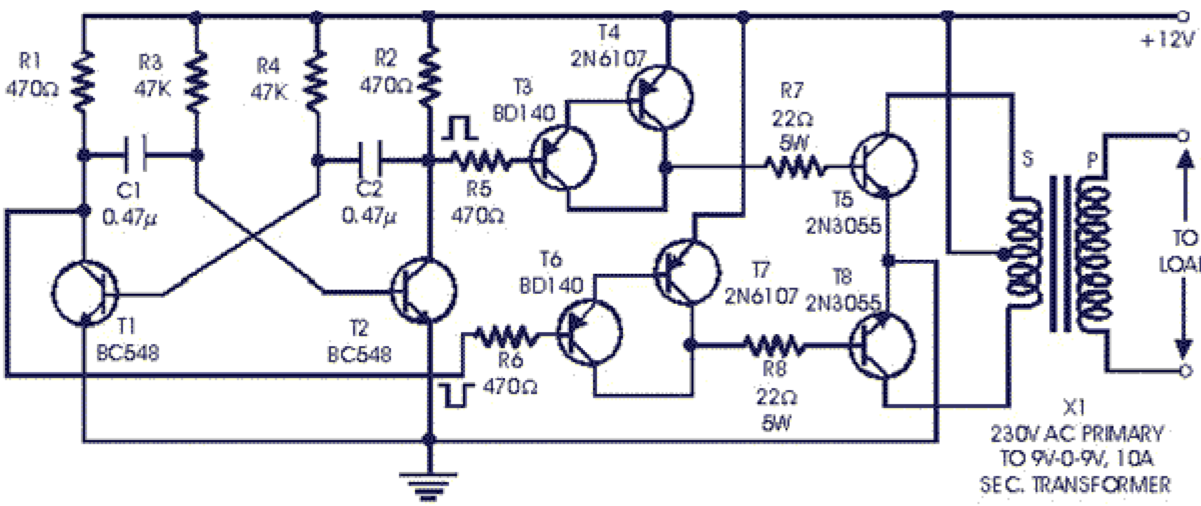


FIG. 3: Laser power supply

Low-Cost Transistorised Inverter



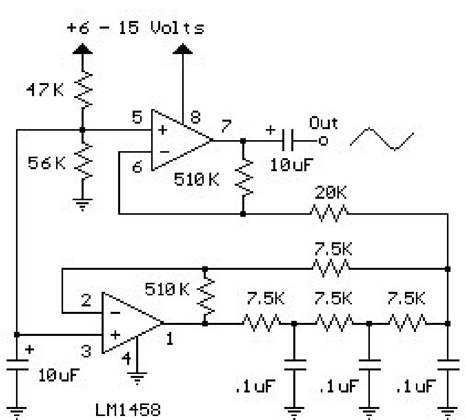
This is an inexpensive fully transistorised inverter capable of driving medium loads of the order of 40 to 60 watts using battery of 12V, 15 Ah or higher capacity. Transistors T1 and T2 (BC548) form a 50Hz multivibrator. For obtaining correct frequency, the values of resistors R3 and R4 may have to be changed after testing. The complementary outputs from collectors of transistors T1 and T2 are given to PNP darlington driver stages formed by transistor pairs T3-T4 and T6-T7 (utilising transistors BD140 and 2N6107). The outputs from the drivers are fed to transistors T5 and T8 (2N3055) connected for push-pull operation.

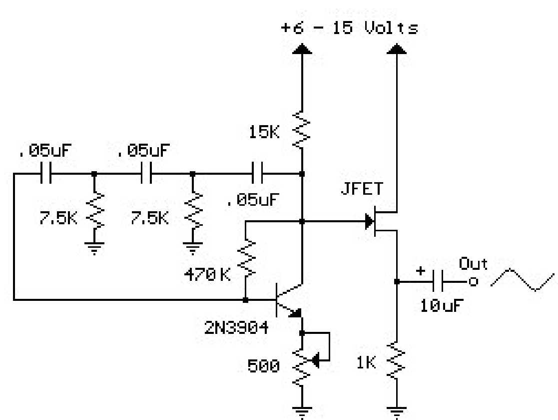
Somewhat higher wattage can be achieved by increasing the drive to 2N3055 transistors (by lowering the value of resistors R7 and R8 while increasing their wattage). Suitable heatsinks may be used for the output stage transistors. Transformer X1 is a 230V primary to 9V-0-9V, 10A secondary used in reverse.

Low Frequency Sinewave Generators

The two circuits below illustrate generating low frequency sinewaves by shifting the phase of the signal through an RC network so that oscillation occurs where the total phase shift is 360 degrees. The transistor circuit on the right produces a reasonable sinewave at the collector of the 3904 which is buffered by the JFET to yield a low impedance output. The circuit gain is critical for low distortion and you may need to adjust the 500 ohm resistor to achieve a stable waveform with minimum distortion. The transistor circuit is not recommended for practical applications due to the critical adjustments needed.

The op-amp based phase shift oscillator is much more stable than the single transistor version since the gain can be set higher than needed to sustain oscillation and the output is taken from the RC network which filters out most of the harmonic distortion. The sinewave output from the RC network is buffered and the amplitude restored by the second (top) op-amp which has gain of around 28dB. Frequency is around 600 Hz for RC values shown (7.5K and 0.1uF) and can be reduced by proportionally increasing the network resistors (7.5K). The 7.5K value at pin 2 of the op-amp controls the oscillator circuit gain and is selected so that the output at pin 1 is slightly clipped at the positive and negative peaks. The sinewave output at pin 7 is about 5 volts p-p using a 12 volt supply and appears very clean on a scope since the RC network filters out most all distortion occurring at pin 1.





MICROMOTOR CONTROLLER

EFY SUNIL KUMAR TESTED

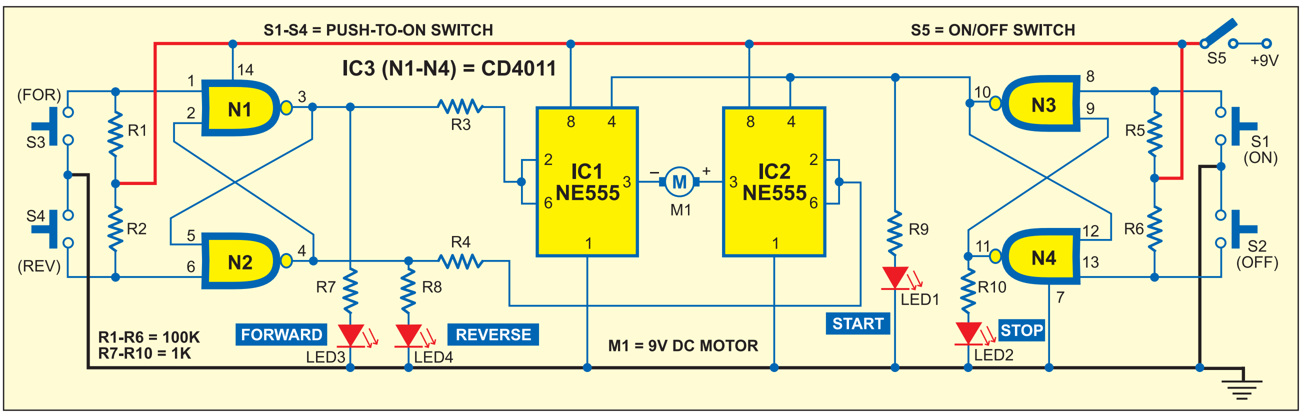
■ **V. DAVID**

Using this circuit, you can control the rotation of a DC micromotor simply by pressing two push-to-on switches momentarily.

The circuit is built around two NE555 ICs (IC1 and IC2) and a quad-NAND IC CD4011 (comprising NAND gates N1 through N4). The NE555 ICs (IC1 and IC2) are configured as inverting buffers. IC CD4011 (IC3) NAND gates are configured as bistable flip-flop. The DC motor to be controlled is connected between the outputs (pin 3) of IC1 and IC2.

Closing switch S5 provides power to the circuit. Now, when you press switch S1 momentarily, pin 10 of IC3 goes high, while its pin 11 goes low. Since pin 10 of IC3 is connected to reset pin 4 of IC1 and IC2, the high output at pin 10 of IC3 will enable IC1 and IC2 simultaneously. When switch S2 is pressed, pin 10 of IC3 goes low, while its pin 11 goes high. The low logic at pin 10 disables both IC1 and IC2.

Switches S3 and S4 are used for forward and reverse motion of the motor in conjunction with switch S1. If you press switch S3 after pressing switch S1, pin 3 of IC3 goes high, while its pin 4 goes low. The motor now starts rotating in the forward direction. However, if you press switch S4 after pressing switch S1, the motor will rotate in reverse direction.



Note. The complete kit of this circuit can be obtained from Kits'n'Spares, 303, Dohil Chambers, 46, Nehru Place, New Delhi 110019; Phone: 011-26430523, 26449577; Website: www.kitsnspares.com; E-mail: kits@efyindia.com. ●

MULTIPURPOSE CIRCUIT FOR TELEPHONES

RANJITH G. PODUVAL

This add-on device for telephones can be connected in parallel to the telephone instrument. The circuit provides audio-visual indication of on-hook, off-hook, and ringing modes. It can also be used to connect the telephone to a CID (caller identification device) through a relay and also to indicate tapping or misuse of telephone lines by sounding a buzzer.

In on-hook mode, 48V DC supply is maintained across the telephone lines. In this case, the bi-colour LED glows in green, indicating the idle state of the telephone. The value of resistor R1 can be changed somewhat to adjust the LED glow, without loading the telephone lines (by trial and error).

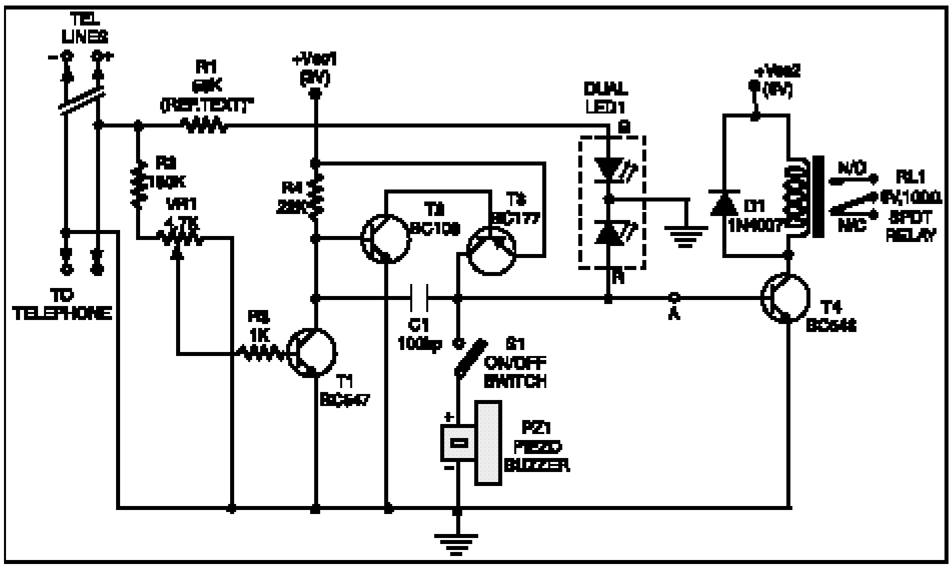
In on-hook mode of the handset, potentiometer VR1 is so adjusted that base of T1 (BC547) is forward biased, which, in turn, cuts off transistor T2 (BC108). While adjusting potmeter VR1, ensure that the LED glows only in green and not in red.

When the hand-set is lifted, the voltage drops to around 12V DC. When this happens, the voltage across transistor T1's base-emitter junction falls below its conduction level to cut it off. As a result transistor pair T2-T3 starts oscillating and the piezo-buzzer starts beeping (with switch S1 in on position). At the same time, the bi-colour LED glows in red.

In ringing mode, the bi-colour LED flashes in green in synchronisation with the telephone ring.

A CID can be connected using a relay. The relay driver transistor can be connected via point A as shown in the circuit. To use the circuit for warning against misuse, switch S1 can be left in *on* position to activate the piezo-buzzer when anyone tries to tap the telephone line. (When the telephone line is tapped, it's like the off-hook mode of the telephone hand-set.)

Two 1.5V pencil cells can provide Vcc1 power supply, while a separate power supply for Vcc2 is recommended to avoid draining the battery. However, a single 6-volt supply source can be used in conjunction with a 3.3V zener diode to cater to both Vcc2 and Vcc1 supplies.



PC-BASED DC MOTOR SPEED CONTROLLER

R. KARTHICK

This circuit allows you to control the speed of a DC motor (in eight levels) from your PC's parallel port. The PC uses a software program to control the speed of the motor.

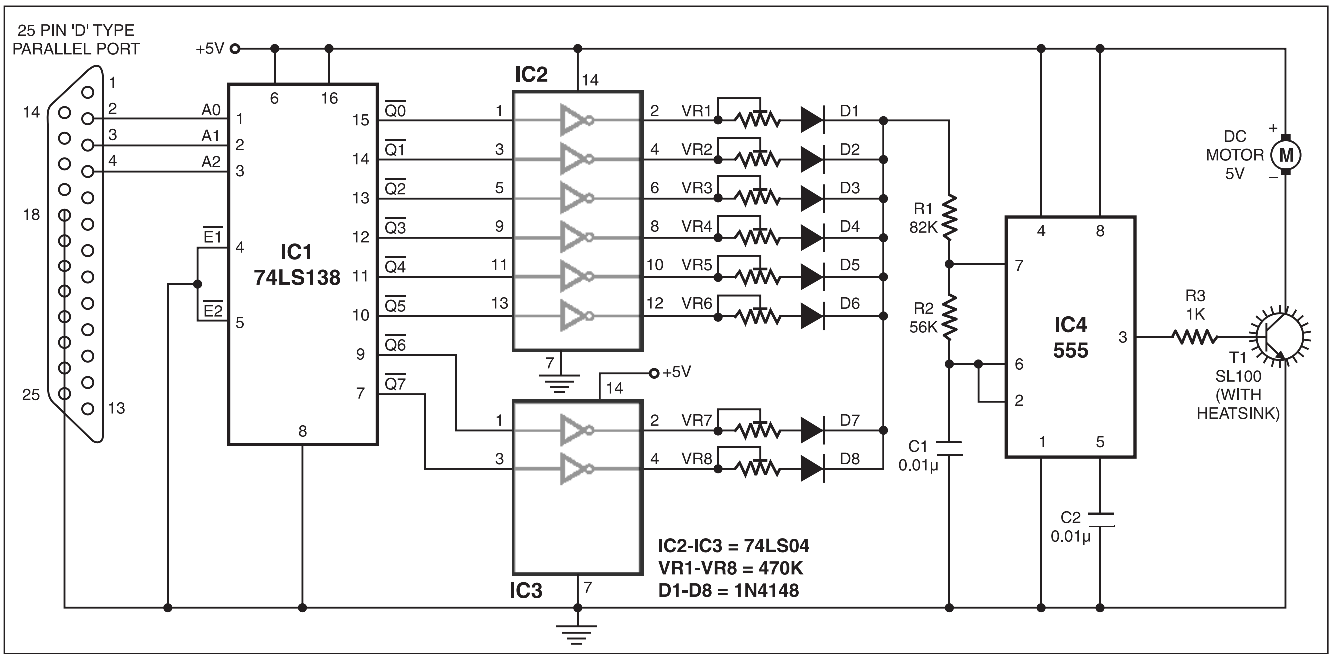
The motor is connected to the PC through an interface circuit. The interface circuit consists of 1-of-8 decoder IC 74LS138 (IC1), hex inverter ICs 74LS04 (IC2 and IC3), resistor networks, timer IC 555 (IC4) and motor driver transistor SL100 (T1). The decoder IC accepts binary weighted inputs A0, A1 and A2 at pins 1, 2 and 3, respectively. With active-low enable input pins 4 and 5 of the decoder grounded, it provides eight mutually exclusive active-low outputs (Q0 through Q7). These outputs are inverted by hex inverters IC2 and IC3.

The resistor network comprising presets VR1 through VR8, resistors R1 and R2 and capacitor C1 are the timing components of timer IC 555 (IC4), which is configured in astable mode. The output of IC4 is a square wave, which is fed to the base of transistor T1 via current-limiting resistor R3. Transistor T1 is used to drive the motor.

The pulse-width modulation (PWM) method is used for efficient control of the motor. The output of the PC is decoded to select a particular preset (VR1 through VR8). The value of the selected preset, along with resistors R1 and R2 and capacitor C1, changes the output pulse width at pin 3 of IC4. Thus the motor speed can be increased/decreased by choosing a particular resistance. For high-power motors, the transistor can be replaced by an IGBT or a power MOSFET.

The software (speedM.c) is written in 'C' language and compiled using Turbo C compiler.

Initially, when the motor is 'off,' the program prompts you to press 'Enter' key to start the motor. Once you press the key, the motor starts running at full speed. After a few seconds, the program asks you to press any key from the keyboard to go to the next screen for controlling the speed of the motor. This screen has options for increasing and decreasing the motor speed and also for exiting from the program. For increasing the speed enter choice 1 and press 'Enter' key, and for decreasing the speed enter choice 2 and press 'Enter' key. This action changes the speed by one step at-a-time and the message "Speed decreased" or "Speed increased" is displayed on the screen. To go to the main menu, again press 'Enter' key.



SPEEDM.C

```
//R.KARTHICK,III ECE,K.L.N.C.E.,MADURAI
//karthick_klnce@rediffmail.com
#include<stdio.h>
#include<conio.h>
int a[7],i,c;
void start(void);
void main(void)
 {
 int P=0x0378,j,c=7,c1,x,y;
clrscr();
outportb(P,0);
textbackground(9);
textcolor(3);
for(x=0;x<=80;x++)
  for(j=0;j<=25;j++)
   {
   gotoxy(x,j);
   cprintf(" ");
   }
for(i=0;i<8;i++)
  a[i]=i;
gotoxy(23,11);
printf("Press Enter to start the motor");
getch();
gotoxy(28,13);
printf("WAIT STARTING MOTOR");
start();
```

```
gotoxy(25,15);
printf("Motor started sucessfully");
gotoxy(22,17);
printf("Press any key for speed control");
getch();
while(1)
 {
 clrscr();
 gotoxy(25,3);
   for(j=0;j<79;j++)
  {
  gotoxy(j+1,2);
  printf("*");
  }
 gotoxy(23,3);
 printf("DC MOTOR SPEED CONTROL USING PC");
 for(j=0;j<79;j++)
  {
  gotoxy(j+1,4);
  printf("*");
  }
  printf("\n");
  printf("\t\t\t1.INCREASE SPEED\n\t\t\t2.DECREASE
SPEED\n\t\t\t3.EXIT") ;
  for(j=0;j<79;j++)
  {
  gotoxy(j+1,8);
  printf("*");
  }
   for(j=0;j<79;j++)
  {
  gotoxy(j+1,10);
  printf("*");
  }
 gotoxy(1,9);
 printf("Enter your choice:");
 scanf("%d",&c1);
 switch(c1)
  {
  case 1:if(c==7)
                  {
                  clrscr();
                  gotoxy(23,13);
                  printf("MOTOR IS RUNNING IN FULL
SPEED");
                         getch();
                         }
                if(c<7)
                  {
                  clrscr();
                  c++;
                  outport(P,a[c]);
                  gotoxy(33,13);
                  printf("SPEED INCREASED");
                  getch();
                  }
                  break;
  case 2: if(c==0)
                  {
                  clrscr();
                  gotoxy(23,13);
    printf("MOTOR IS RUNNING IN LOW SPEED");
                  getch();
                         }
                if(c>0)
                  {
                  clrscr();
                  c--;
                  outport(P,a[c]);
                  gotoxy(33,13);
                  printf("SPEED DECREASED");
                  getch();
                  }
                  break;
   case 3   :
                 for(j=c;j>=0;j--)
                  {
                 outportb(0X0378,j);
                 delay(100);
                  }
                 outportb(P,0);
                 clrscr();
                 gotoxy(17,13);
                 textcolor(2);

    cprintf("KARTHICK.R\nECE\nK.L.N.COLLEGE OF
ENGG\nMADURAI.");
                 getch();
                 exit(1);
    }
  }
 }

 void start()
  {
  outportb(0x0378,0);
  for(i=0;i<8;i++)
   {
   outportb(0X0378,i);
   delay(1000);
   }
  }
```

PC-BASED OSCILLOSCOPE

M.M. VIJAI ANAND

This circuit conditions different signals of frequency below 1 kHz and displays their waveforms on the PC's screen. The hardware is used to condition the input waveform and convert it to the digital format for interfacing to the PC. The software for acquiring the data into the PC and displaying the same on its screen is written in Turbo C.

The input waveform (limited to 5V peak-to-peak) is first applied to a full-wave rectifier comprising op-amps A1 and A2 of quad op-amp LM324 (IC4) and a zero-crossing detector built around LM3914 dot/bar display driver (IC8) simultaneously.

The full-wave rectifier rectifies the input signal such that the negative half cycle of the input signal is available in the positive side itself, so both the half cycles are read as positive when it is given as input to the ADC. During positive half cycle, diode D3 is on and diode D4 is off, and op-amps A1 and A2 act as inverters. Thus the output is a replica of the input. During the negative half cycle, diode D3 is off and diode D4 is on. With R2 = R3 = R4 = R5 = R6 = R = 330 ohms, the voltage (V) at inverting pin 2 of op-amp A1 is related to the input voltage (Vi) as follows:

$$Vi/R + V/(2R) + V/R = 0$$

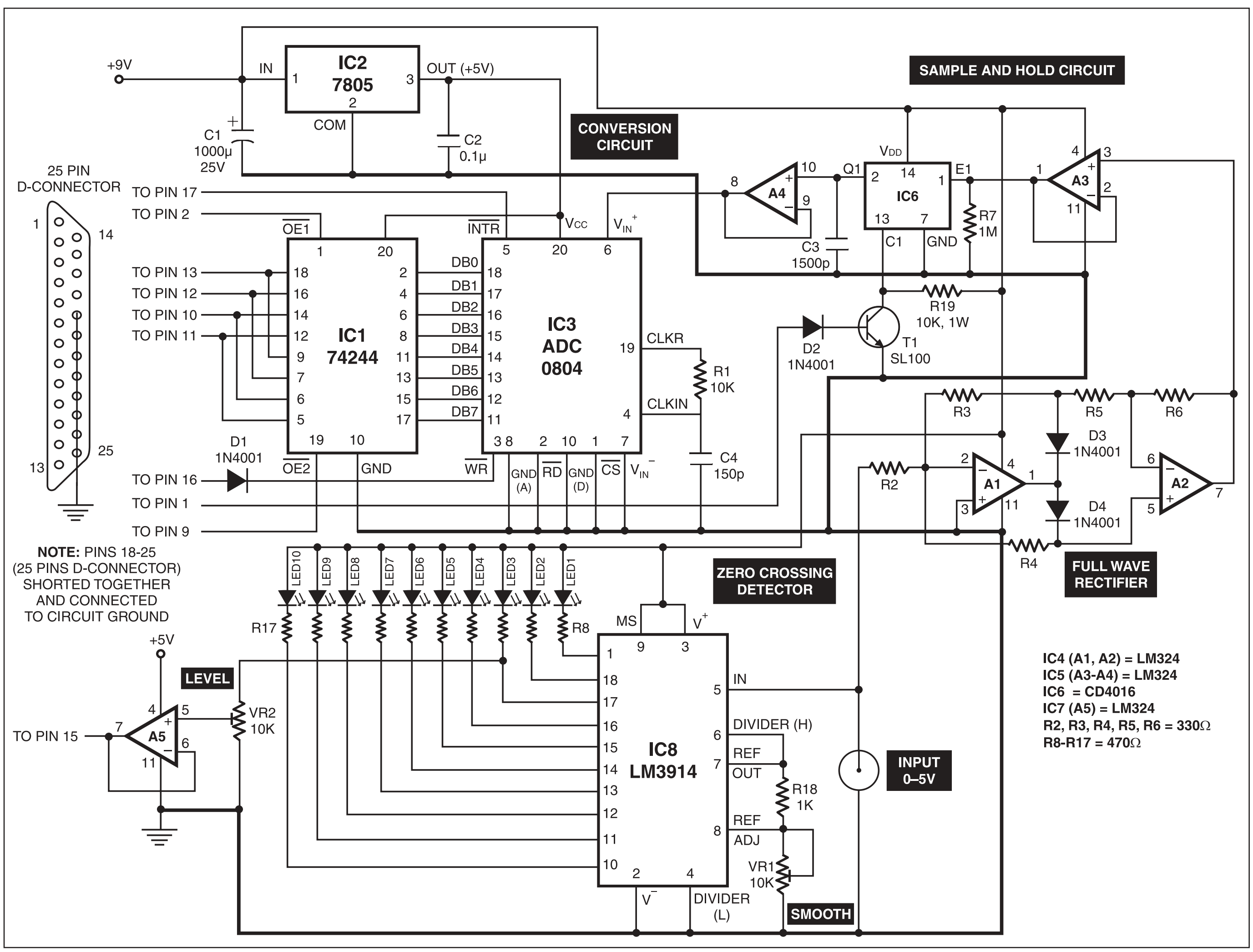
$$V = -(2/3)Vi$$

The final output voltage (Vo) at pin 7 of op-amp A2 is given by the following relationship:

$$Vo = (1 + R/2R)(-2Vi/3) = -Vi$$

As Vi is negative, the output voltage is positive.

The zero-crossing detector detects whether the cycle is positive or negative. It is the most critical part of the circuit and if it operates improperly, the symmetry of the analogue signal displayed in the PC monitor gets affected. At the zero-crossing instant when the input signal transits to negative side, the zero-crossing detector informs the PC by taking pin 15 of 25-pin 'D' connector of the parallel port high.



The input at pin 15 of 'D' connector goes low when the input signal transits to positive side. The zero-crossing detector communicates with the PC through bit D3 of the status port 379Hex**.**

The zero-crossing detector has been realised using LM3914 IC. You may adjust VR1 such that the last LED (LED10) goes off when the input signal transits negative side of the input waveform. The LM3914 itself rectifies the input signal and allows only positive half of the cycle.

The output from the full-wave rectifier is applied to the input of a sample-and-hold circuit comprising op-amps A3 and A4 of the LM324 (IC5), capacitor C3, transistor T1 (SL100), and analogue switch IC6 (CD4016). This circuit samples the input signal, i.e. it divides the waveform into a number of voltages or points and inputs each voltage level (with a delay) to the ADC for conversion into the digital format. Op-amps A3 and A4, along with a switch from IC CD4016 and a 1500pF capacitor with sampling time of 20 µs, are used as voltage followers/buffers.

When the base of transistor T1 is made low via strobe pin 1 (bit Do of I/O port 37A) of 25-pin D connector of the parallel port, the transistor stops conducting and the voltage at its collector goes high. The high voltage at the collector of transistor T1 closes the switch inside CD4016. As a consequence, the analogue input signal is applied to the capacitor, which charges towards the signal voltage.

When the switch is subsequently opened by applying a logic-high voltage from pin 1 of 'D' connector to the base of transistor T1, the capacitor retains the voltage with a loss of about 20 mV/sec and this voltage is given to input pin 6 of the ADC0804 (IC3) via buffer A4 for conversion to the digital format. When the number of sampling points in the input signal waveform is increased, the reconstructed waveform becomes more accurate.

The ADC0804 is compatible with microprocessors. It is a 20-pin IC that works with 5V supply. It converts the analogue input voltage to 8-bit digital output. The data bus is tristate buffered. With eight bits, the resolution is 5V/255 = 19.6 mV.

The inbuilt clock generator circuit produces a frequency of about 640 kHz with R1 = 10 kilo-ohms and C4 = 150 pF, which are the externally connected timing components. The conversion time obtained is approximately 100 µs. The functions of other pins are given below:

Pin 1 ($\overline{CS}$): This is active-low chip-select pin.

Pin 2 ($\overline{RD}$): This active-low pin enables the digital output buffers. When high, the 8-bit bus will be in Hi-Z state.

Pin 3 ($\overline{WR}$): This active-low pin is used to start the conversion.

Pin 9 (Vref/2): This is optional input pin. It is used only when the input signal range is small. When pin 9 is at 2V, the range is 0-4V, i.e. twice the voltage at pin 9.

Pin 6 (V+), Pin 7(V-): The actual input is the difference in voltages applied to these pins. The analogue input can range from 0 to 5V.

In this circuit, pins 1 and 2 are always made low, so the IC and the buses are always enabled. Pin 9 is made open, as we use analogue input with 0-5V range. Pin 7 is grounded.

Pin 5 ($\overline{INTR}$): This active-low pin indicates the end of conversion. It is connected to pin 17 (bit D3 of I/O port 37A) of 'D' connector. (Note that this bit is inverted.)

The start-of-conversion command via pin 16 of 'D' connector is applied to pin 3 of the ADC0804. Since we cannot read 8-bit digital data output from ADC through the 4-bit status port at a time, we divide it in two 4-bit parts and read. Hence the ADC data output is multiplexed through two 4-bit sections of octal buffers of IC1 (74244) with the help of output-enable signals from pins 2 and 9 of 'D' connector to pins 1 and 19 ($\overline{OE1}$ and $\overline{OE2}$, respectively) of IC1. The digital data output from IC1 is interfaced to the PC via pins 13 (D4), 12 (D5), 10 (D6), and 11 (D7) of status input port 379H of 'D' connector.

The circuit uses 9V and 5V regulated DC supply voltages as shown in the circuit diagram.

A PC printer port is an inexpensive platform for implementing low-frequency data acquisition projects. Each printer port consists of data, status, and control port addresses. These addresses are in sequential order; for example, if the data port address is 0x0378, the corresponding status port address is 0x0379 and the control port address is 0x037a. The port addresses for parallel ports are summarised below:

Printer	Data port	Status port	Control port
LPT1	0x0378	0x0379	0x037a
LPT2	0x0278	0x0279	0x027a
LPT3	0x03bc	0x03bd	0x03be

(***EFY Lab note.*** For details of the parallel port pins, refer 'PC-based Dial Clock with Timer' project published in June 2002 issue of EFY.)

The software, written in C programming language, is user-friendly and easy-to-understand. It gets data from the developed hardware circuit and displays it in the graphical screen with some changes.

The C program includes two user-defined functions with the main function: graphics( ) and settings( ). The settings( ) function is used to adjust the voltage and time scale. The graphics( ) function is used to display the waveform on the screen. The sample control signal is used to close the switch in the sample-and-hold circuit, so the capacitor charges towards the analogue input voltage. After the sampling is over, the switch is opened using the same signal. Then the start-of-conversion control signal is given to start the conversion. The sampling time is approximately 20 µs and the conversion time is approximately 100 µs.

After the conversion is over, the 8-bit binary data for the specific voltage sample is available in the data bus of the ADC. Since the PC accepts only 4-bit data through the status port (379H), the 8-bit data must be split into two 4-bit data, which are accepted one after another. This is done by IC 74244, which is controlled by D0 and D7 bits of the data port. Then the two 4-bit data are packed to get the final 8-bit data.

The default BGI directory path is set as 'c:\tc\bgi'. The sampling time is decided by the 'for' loop that uses the samp value. The maximum delay produced should be greater than 20 µs, which is the maximum acquisition time of the capacitor. When the sample value is increased, the number of points on the input signal decreases and therefore the accuracy decreases. The time scale may be calibrated with 50Hz sine wave as reference.

This circuit costs around Rs 400.

PROGRAM IN 'C' FOR PC OSCILLOSCOPE

```
/* PROGRAM FOR PC OSCILLOSCOPE */
/*by M.M.VIJAI ANAND B.E (E.E.E) C.I.T */
#include < dos.h >
#include < time.h >
#include < stdio.h >
#include  < graphics.h >
#include < string.h >
#include < stdlib.h >
#define data 0x0378
#define stat 0x0379
#define cont 0x037a
```

```
void graphics(int[],int[]);        //FUNCTION TO DISPLAY GRAPH AND WAVEFORM

void settings();                   //FUNCTION TO CHANGE THE SETTINGS(TIME AND VOLTAGE)

long int samp = 7000;    //PLEASE CHECK THESE VALUES WHEN CONVERSION IS
                                         //        NOT PROPER( + - 3000)

float scale = 1;
float times = 1;
char again = 'a';
int number = 800;

void  main()
{
int i,j,k,a[1700],b[1700],c[1700],e[1700]; //This value 1700 is given when we want to compress the waveform

                //done when we compress the time scale
long int b1;
clrscr();
settings();
while(again = = 'a')
{
for(i = 0;i < number;i + + )
{
outportb(cont,0x05^0x0b);
outportb(cont,0x04^0x0b);
e[i] = (inportb(stat)^0x80)&0x08;
for(b1 = 0;b1 < = samp;b1 + + )                //sampling time is approximately 50 µsec
{}

outportb(cont,0x05^0x0b);
outportb(cont,0x01^0x0b);
outportb(cont,0x05^0x0b);
while((inportb(cont)&0x08) = = 0x00)  //converstion time is approximately 100 µsec
{
}

outportb(data,0xf0);
a[i] = (inportb(stat)^0x80)&0xf0;
outportb(data,0x01);
b[i] = (inportb(stat)^0x80)&0xf0;
outportb(data,0xff);
}
for(i = 0;i < number;i + + )
{
a[i] = a[i] > > 4;
c[i] = a[i] + b[i];
c[i] = c[i]*0.0196*45/scale;
}
graphics(c,e);
}

}

void graphics(int a1[],int e1[])
{
int gd = DETECT,gm,max,may,a,b,c,im,error,get = 5;

char str[10],*st = "-",d;

clrscr();
initgraph(&gd,&gm,"c:\\tc\\bgi");                //use default bgi path
error = graphresult();
if(error ! =  grOk)
{
printf("Graphics error %s /n",grapherrormsg(error)); //reports error when

                //graphics is not set
printf("PRESS ANY KEY TO EXIT");
getch();
exit(1);
}
setbkcolor(LIGHTCYAN);
setcolor(MAGENTA);

settextstyle(0,0,2);
max = getmaxx();
may = getmaxy();
may = may-20;
outtextxy(0,may,"OSCILLOSCOPE");
settextstyle(0,0,1);
setcolor(BLUE);
outtextxy(max-200,may + 2,"press  'a'  for  next sample");
setcolor(BROWN);
outtextxy(max-200,may + 10,"press any key to exit");
setcolor(GREEN);
settextstyle(0,0,0);
for(a = 0;a < = may;a + = get)
{line(0,a,800,a);
}
for(a = 0;a < = max;a + = get)
{
line(a,0,a,may);
}
setcolor(BROWN);
setlinestyle(0,3,0);
line(max/2,0,max/2,may);
line(0,may/2,max,may/2);
setcolor(RED);
for(a = 0,c = 0;a < = max;a + = 50,c + + )
{
putpixel(a,may/2,BLUE);
itoa((a-c*30)*times/2,str,10);
outtextxy(a + 3,may/2 + 3,str);
}
for(b = (may/2)-45,c = 1;b > = 0;b- = 45,c + + )
{
itoa((c*scale),str,10);
putpixel((max/2),b,BLUE);
outtextxy((max/2) + 3,b + 3,str);
}
for(b = (may/2) + 45,c = 1;b < = 800;b + = 45,c + + )
{
itoa((c*scale),str,10);
strcat(st,str);
putpixel((max/2),b,BLUE);
outtextxy((max/2) + 2,b + 2,st);
strcpy(st,"-");
}
setcolor(MAGENTA);

outtextxy(max-80,may/2 + 30,"time(msec)");
settextstyle(0,1,0);
outtextxy((max/2)-10,0,"volt(s)");

setlinestyle(0,0,0);
setcolor(RED);
moveto(0,may/2);
for(b = 0,c = 0;b < = number;c + = 1, b + + )
{
if(e1[b]! = 0x08)
{
lineto(c*times,((may/2)-a1[b]));
}
else
{
lineto(c*times,((may/2) + a1[b]));
}
}
again  =  getch();
closegraph();
restorecrtmode();

}

void settings()
{
int gd = DETECT,gm,error,max,may,b;
char c,d,e[2],m,*n;
times = 1;
initgraph(&gd,&gm,"c:\\tc\\bgi");        //default bgi directory path
error = graphresult();
if(error ! =  grOk)
{
printf("Graphics error %s /n",grapherrormsg(error));
printf("PRESS ANY KEY TO EXIT");
getch();
exit(1);
}
max = getmaxx();
setbkcolor(LIGHTBLUE);
settextstyle(1,0,0);
setcolor(BROWN);
outtextxy(max/2-60,20,"SETTINGS");
line(0,60,800,60);
setcolor(MAGENTA);
settextstyle(1,0,1);
outtextxy((max/4)-70,80,"Voltage Scale");
settextstyle(0,0,0);
setcolor(BROWN);
outtextxy(10,120,"DEFAULT      :");
outtextxy(10,120,"               1 unit  =  1 volt");
setcolor(RED);
outtextxy(10,170,"TYPE 'C' TO CHANGE AND 'D' TO DEFAULT");
c = getch();
if(c = = 'c')
{
outtextxy(10,200,"TYPE 1  for   1 unit  =  2 volt");
outtextxy(10,240,"TYPE 2  for   1 unit  =  4 volt");
outtextxy(10,300,"TYPE 3  for   user defined");
switch(getch())
{
 case '1' :
           { scale = 2;
            break;
           }
 case '2' :
           {scale  =  4;
           break;
           }
 case '3' :
 {
  outtextxy(10,340,"TYPE  VALUES  FROM  1  TO  9 (minimize) or  m to (magnify)");
  d = getch();
  if(d = = 'm')
    {
    outtextxy(10,360,"TYPE a (1 unit  =  0.5 volt) or b (1 unit  =  0.25 volt)");
    switch(getch())
           {
            case 'a':
               {
               scale = 0.5;
               break;
               }
            case 'b':
               {
               scale = 0.25;
               break;
               }
          }
    }
  else
  {  e[0] = '0';
    e[1] =  '0';
    e[2] = d;
  scale = atoi(e);
  break;
  }
  }
  }
 }
setcolor(BROWN);
outtextxy(10,380,"TYPE C TO CHANGE TIME SETTINGS");
m = getch();
if( m = = 'c')
{
cleardevice();
outtextxy(10,20,"X AXIS 1 unit =  10msec CHANGE TO x(10msec)");
outtextxy(10,40,"TYPE 'a' IF x IS (2 to 9) ,'b' IF x IS (10 to 99) AND 'c' IF x IS (.5 TO .9)");
switch(getch())
    {
    case 'a':
      outtextxy(10,60,"x value is ....");
      n[0] = getch();
      times = atoi(n);
      itoa(times,n,10);
      outtextxy(10,70,n);
      break;
    case 'b':
      outtextxy(10,60,"x value is ....");
      n[0] = getch();
      n[1] = getch();
      times = atoi(n);
      itoa(times,n,10);
      outtextxy(10,70,n);
      break;

   case 'c':
           outtextxy(10,60,"x value is...");
           getch();
           n[0] = getch();
           times = atoi(n)*0.1;
           outtextxy(10,70,"scale decremented");
           break;

}
number = 800;
if(times < 1)
{number = number/times;
}
getch();
}
closegraph();
restorecrtmode();
}
```

PENDULUM DISPLAY

K.P. VISWANATHAN

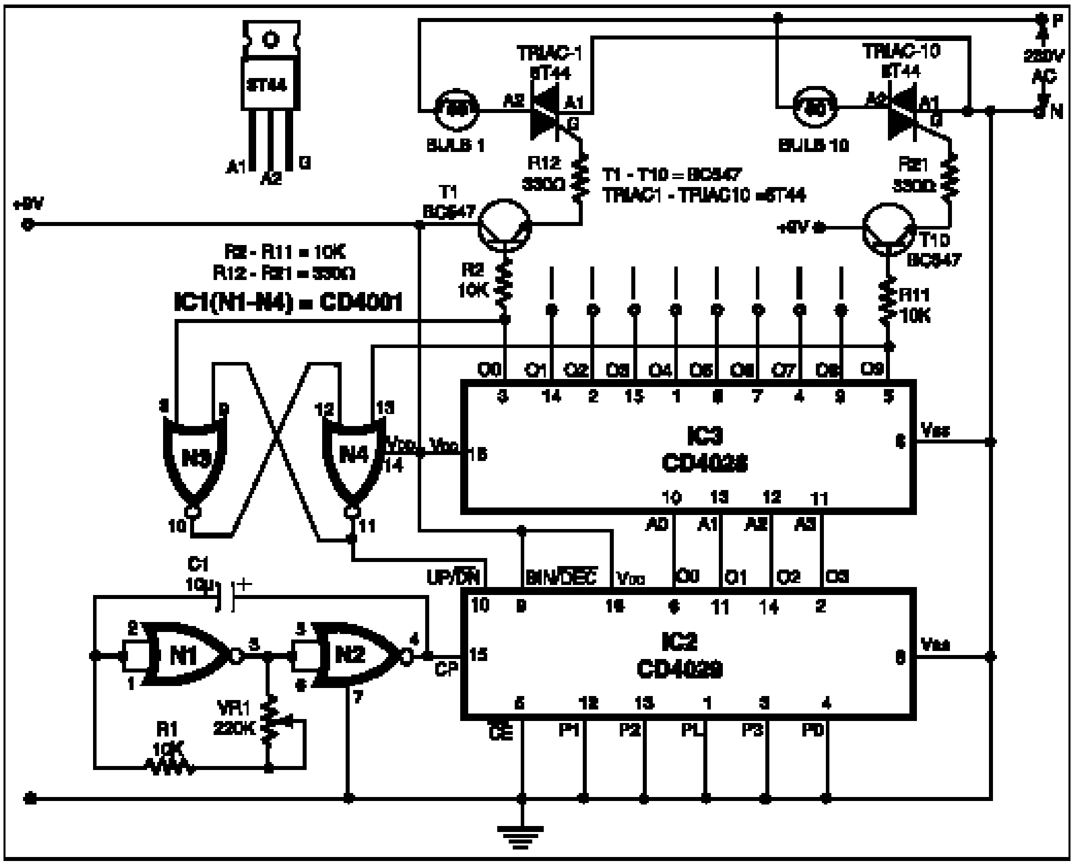
The circuit presented here can be used for producing eye-catching effects like 'pendulum' and 'dashing light'. To and fro motion of a pendulum can be simulated by arranging ten bulbs in a curved fashion and lighting them up sequentially, first in one direction and then in the other, using this circuit. For pendulum effect, the frequency of oscillator should be quite low.

Similarly, one may create a dashing light effect by using 19 bulbs and connecting them in such a way that bulb number 1 and 19, 2 and 18, 3 and 17, so on are in parallel. For achieving the dashing light effect, the oscillator frequency should be comparatively high.

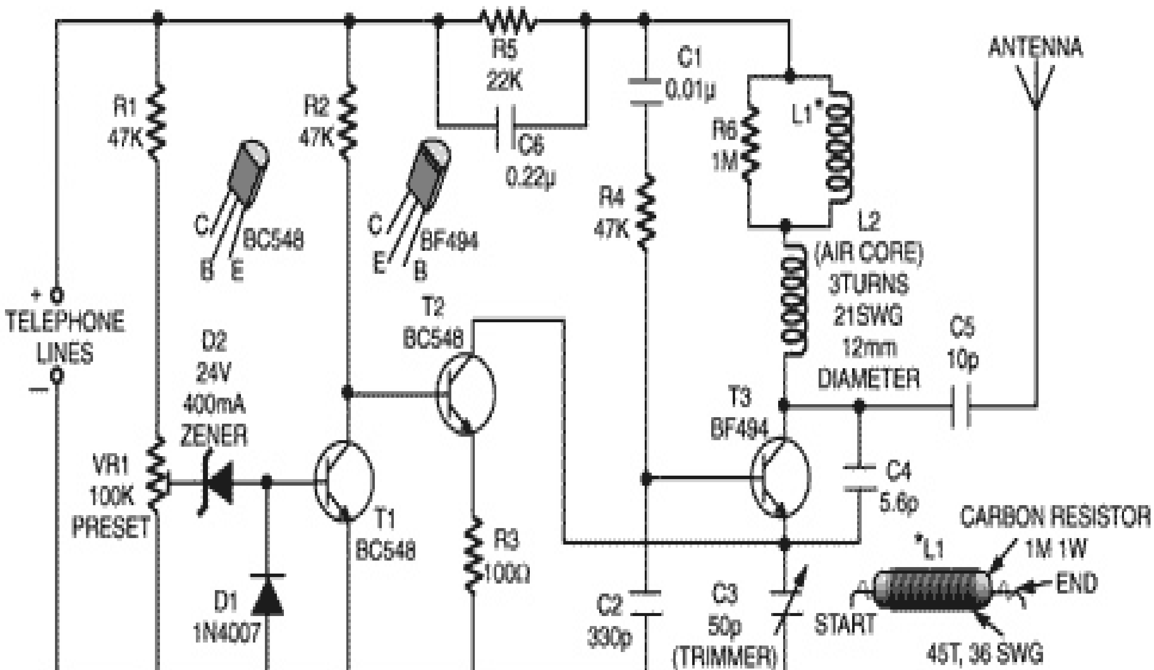
In this circuit NOR gates N1 and N2 form an oscillator whose period can be adjusted through potmeter VR1. Oscillator output is fed to clock pin 15 of IC2 (CD4029), which is a binary/BCD up/down counter. As long as pin 10 of IC2 is at logic 1, it counts up; when it changes to logic 0, it counts down. This changeover is explained below.

The BCD outputs of IC2 are connected to IC3 (CD4028), which is a 1-of-10 decoder. As per sequential BCD inputs (up or down), outputs of IC3 go high and trigger the triacs (Triac1 through Triac10) via corresponding transistors (T1 through T10) to light up the bulbs connected to them.

Initially, when output O0 of IC3 goes high, the output of flip-flop formed by NOR gates N3 and N4 goes high, thus keeping pin 10 of IC2 at logic 1, and the counter counts up. Subsequently, when output O9 become high, the flip-flop is toggled and pin 10 of IC2 is pulled to logic 0, and the counter starts counting down. The cycle repeats endlessly.



Phone Broadcaster



Here is a simple yet very useful circuit which can be used to eavesdrop on a telephone conversation. The circuit can also be used as a wireless telephone amplifier.

One important feature of this circuit is that the circuit derives its power directly from the active telephone lines, and thus avoids use of any external battery or other power supplies. This not only saves a lot of space but also money. It consumes very low current from telephone lines without disturbing its performance. The circuit is very tiny and can be built using a single-IC type veroboard that can be easily fitted inside a telephone connection box of 3.75 cm x 5 cm.

The circuit consists of two sections, namely, automatic switching section and FM transmitter section.

Automatic switching section comprises resistors R1 to R3, preset VR1, transistors T1 and T2, zener D2, and diode D1. Resistor R1, along with preset VR1, works as a voltage divider. When voltage across the telephone lines is 48V DC, the voltage available at wiper of preset VR1 ranges from 0 to 32V (adjustable). The switching voltage of the circuit depends on zener breakdown voltage (here 24V) and switching voltage of the transistor T1 (0.7V). Thus, if we adjust preset VR1 to get over 24.7 volts, it will cause the zener to breakdown and transistor T1 to conduct. As a result collector of transistor T1 will get pulled towards negative supply, to cut off transistor T2. At this stage, if you lift the handset of the telephone, the line voltage drops to about 11V and transistor T1 is cut off. As a result, transistor T2 gets forward biased through resistor R2, to provide a DC path for transistor T3 used in the following FM transmitter section.

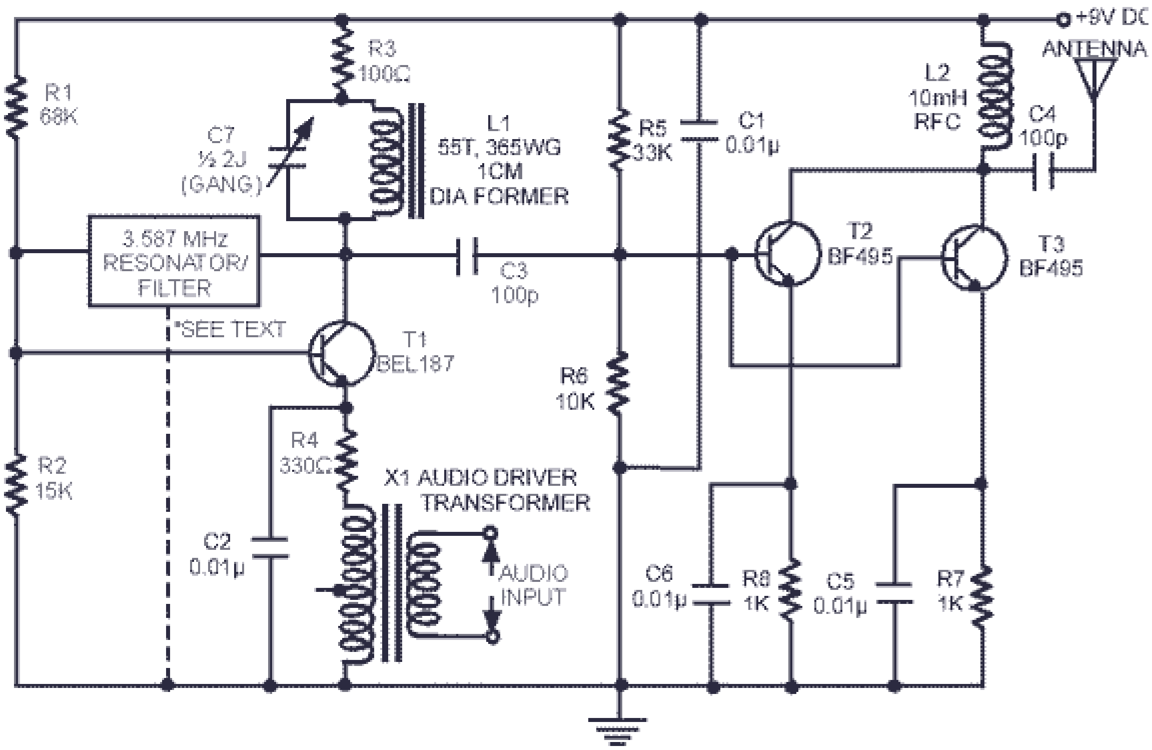
The low-power FM transmitter section comprises oscillator transistor T3, coil L1, and a few other components. Transistor T3 works as a common-emitter RF oscillator, with transistor T2 serving as an

electronic ‘on’/‘off’ switch. The audio signal available across the telephone lines automatically modulates oscillator frequency via transistor T2 along with its series biasing resistor R3. The modulated RF signal is fed to the antenna. The telephone conversation can be heard on an FM receiver remotely when it is tuned to FM transmitter frequency.

Lab Note: During testing of the circuit it was observed that the telephone used was giving an engaged tone

when dialed by any subscriber. Addition of resistor R5 and capacitor C6 was found necessary for rectification of the fault.

Powerful AM Radio Transmitter



The circuit for a powerful AM transmitter using ceramic resonator/filter of 3.587 MHz is presented here. Resonators/filters of other frequencies such as 5.5 MHz, 7 MHz and 10.7 MHz may also be used. Use of different frequency filters/resonators will involve corresponding variation in the value of inductor used in the tank circuit of oscillator connected at the collector of transistor T1.

The AF input for modulation is inserted in series with emitter of transistor T1 (and resistor R4) using a transistor radio type audio driver transformer as shown in the circuit. Modulated RF output is developed across the tank circuit which can be tuned to resonance frequency of the filter/resonator with the help of gang condenser C7. The next two stages formed using low-noise RF transistors BF495 are, in fact, connected in parallel for amplification of modulated signal coupled from collector of transistor T1 to bases of transistors T2 and T3. The combined output from collectors of T2 and T3 is fed to antenna via 100pF capacitor C4.

The circuit can be easily assembled on a general-purpose PCB. The range of the transmitter is expected to be one to two kilometers. The circuit requires regulated 9-volt power supply for its operation. Note: Dotted lined indicates additional connection if a 3-pin filter is used in place.

DESIGNING AN RF PROBE

N.S. HARISANKAR, VU3NSH

Radio frequency probe is used to directly measure the level of RF RMS voltage present across two points. It is one of the most useful test instruments for home brewers as well as for communication equipment service/design labs.

RF voltage level being measured provides useful information only when the probe has been designed for use with a specific multimeter. The design of RF probe is a function of the meter we intend to use it with. If a meter with a different input resistance is used with the probe, the reading will be incorrect. The value of R_X (refer figure) is so chosen that when this resistor is connected in parallel with input resistance of the multimeter, the peak value is about 1.414 times the RMS voltage. Resistor R_X has to drop this excess voltage so that meter indication is accurate. If we know the input resistance of the meter, we can calculate the value of R_X with the help of the following relationship:

Let meter DC input resistance

$$X\ 1.414 = R_Y$$

Then $R_X = R_y$ - meter DC input resistance

For example, if meter input resistance is 20 meg-ohm, R_y = 28.28 meg-ohm and R_X = 8.28 meg-ohm.

We can convert the RF voltage level (E) so measured across a given load resistance (R) to RF watts (W) using the following relationship:

Power P = E^2 / R watts (W)

For example, if RF probe voltage reading across a load resistance of 50 ohms is found to be, say, 15.85 volts, the power in the load = 15.85 x 15.85 / 50 = 5W approx. In other words, for 5-watt power in a 50-ohm load, the voltage across the load is 15.85 volts.

The rectified DC voltage at the cathode of diode D1 is at about the peak level of the RF voltage at the tip of the probe. Use shielded cable in between the probe output and meter. It will act as feed-through capacitance and thus avoid RF interference. The maximum RF input voltage level depends on the peak inverse voltage (PIV) of diode D1. The shielded lead length is too large to give accurate results at UHF. Please refer Tables I and II for ready conversion of RF voltage level (RMS) to equivalent power across a 50-ohm load and deduction of R_x value for a given meter's DC input resistance respectively.

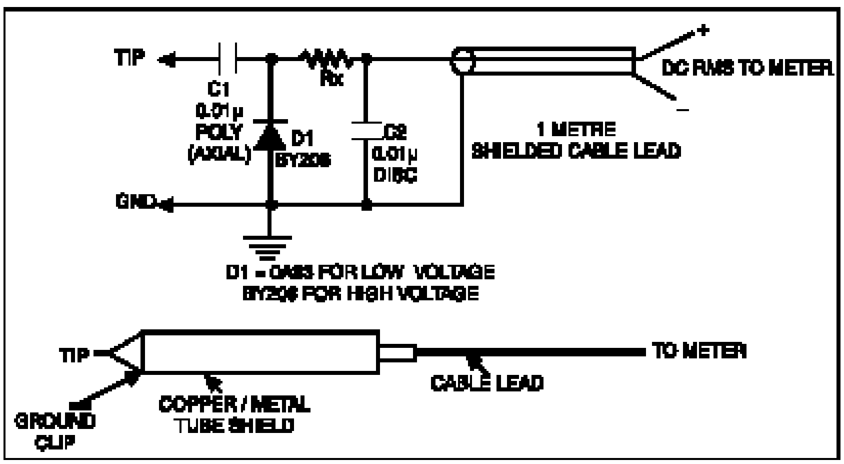
TABLE I

Voltage to Watts Conversion for 50 ohms Termination

RMS (V)	RF Power (W)
2.24	0.1
3.88	0.3
5.0	0.5
7.08	1
12.25	3
15.90	5
20.0	8
22.4	10
38.75	25
41.85	35
50.0	50

Table II

Meter DC Impedence	Rx
20 Meg-ohm	8.25 Meg-ohm
10 Meg-ohm	4.14 Meg-ohm
1 Meg-ohm	41.4 kilo-ohm
20 kilo-ohm	8.28 kilo-ohm



SMART FLUID LEVEL INDICATOR

THOMMACHAN THOMAS

RUPANJANA

Most of the fluid level indicator circuits use a bar graph or a seven-segment display to indicate the fluid level. Such a display using LEDs or digits may not make much sense to an ordinary person. The circuit presented here overcomes this flaw and displays the level using a seven-segment display—but with a difference. It shows each level in meaningful English letters. It displays the letter E for empty, L for low, H for half, A for above average, and F for full tank .

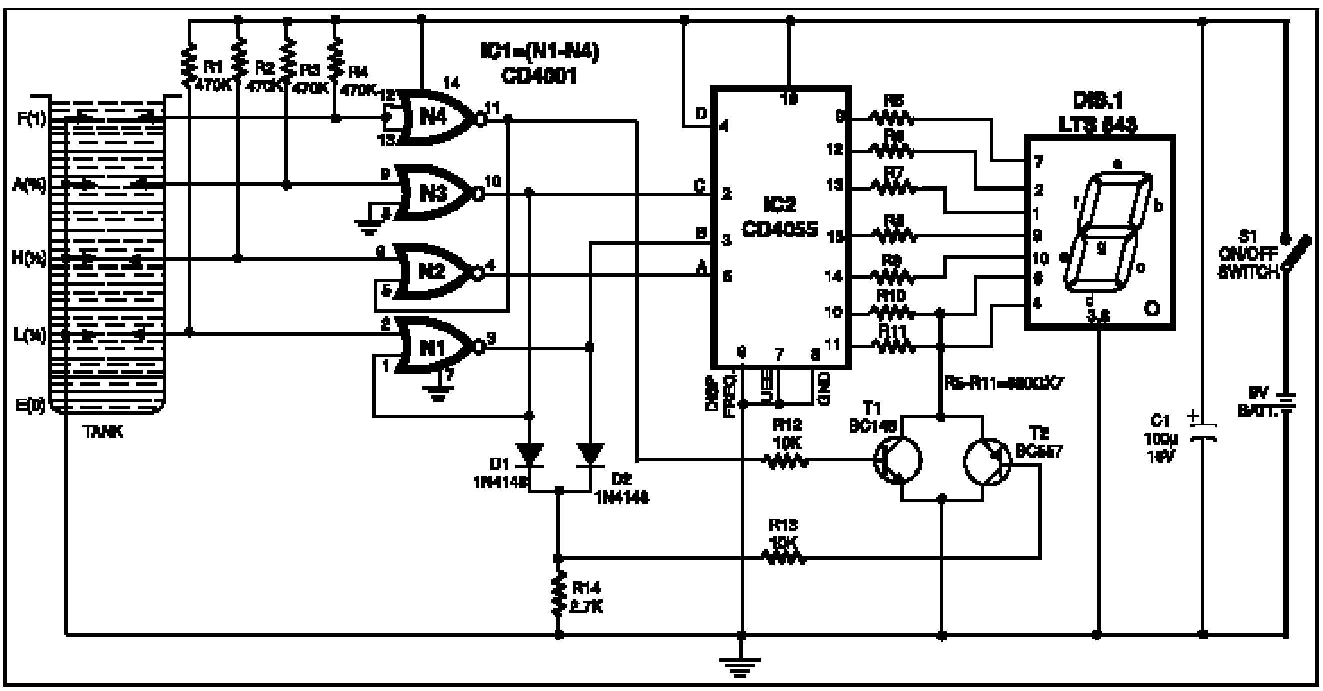
The circuit is built using CMOS ICs. CD4001 is a quad. NOR gate and CD4055 is a BCD to seven-segment decoder and display driver IC. This decoder IC is capable of producing some English alphabets besides the usual digits 0 through 9. The BCD codes for various displays are given in Table I. The BCD codes are generated by NOR gates because of their interconnections as the sensing probes get immersed in water. Their operation being self-explanatory is not included here.

Note that there is no display pattern like E or F available from the IC. Therefore to obtain the pattern for letters E and F, transistors T1 and T2 are used. These transistors blank out the unnecessary segments from the seven-segment display. It can be seen that letter E is generated by blanking 'b' and 'c' segments of the seven-segment display while it decodes digit 8. Letter F is obtained by blanking segment 'b' while it decodes letter P.

As CMOS ICs are used, the current con-

TABLE I

D	C	B	A	DISPLAY
L	L	L	L	0
L	L	L	H	1
—	—	—	—	2
—	—	—	—	3
—	—	—	—	4
—	—	—	—	5
—	—	—	—	6
—	—	—	—	7
H	L	L	L	8
H	L	L	H	9
H	L	H	L	L
H	L	H	H	H
H	H	L	L	P
H	H	L	H	A
H	H	H	L	—
H	H	H	H	BLANK



sumption is extremely low. This makes it possible to power the circuit from a battery. The input sensing current through the fluid (with all the four probes immersed in water) is of the order of 70 µA, which results in low rate of probe deterioration due to oxidation as also low levels of electrolysis in the fluid.

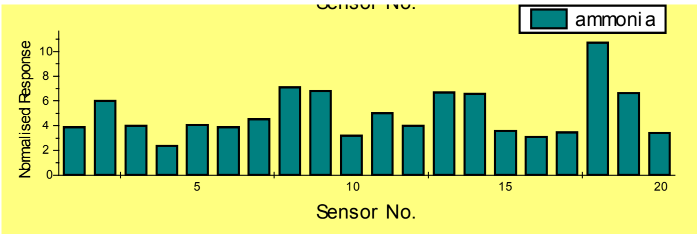
Note: This circuit should not be used with inflammable or highly reactive fluids.

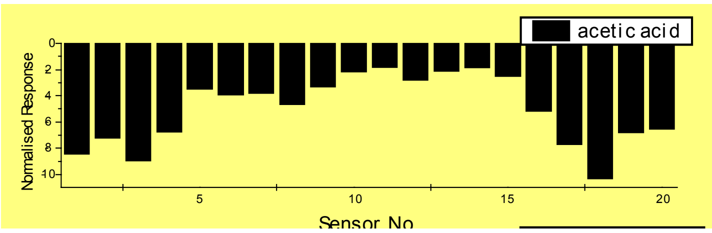
Sensing Smell

Smell can be used to detect and prevent crimes. Dogs are used to find dead bodies, detect drugs or explosives and can even identify people by their smell. Scientists and engineers are working on machines that can sense smell and so can be used at airports to detect explosives or drugs or to identify people before letting them into a building.

A smell is a mixture of chemicals in the air; animals and machines identify smells by using a number of different sensors. Smell sensors are sensitive to a small number of chemicals. If lots of different sensors are used the smell can be identified by measuring how much each type of sensor is affected.

Here is how 20 different sensors responded to ammonia, a substance in a lot of cleaning products. Notice that sensor No 4 gave a reading of 2.



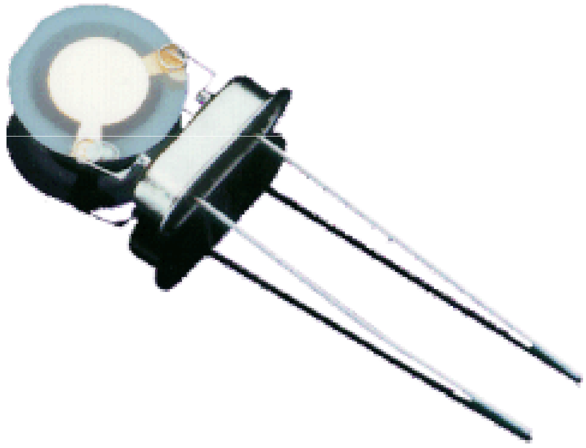


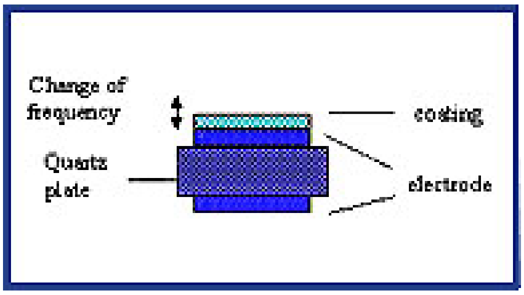
Here is how the same 20 sensors responded to acetic acid the substance in vinegar. Notice that sensor No 4 now gives a reading of –7.

1. What reading does sensor No 14 give for ammonia?
2. What reading does sensor No 15 give for acetic acid?
3. Which sensor is most sensitive to ammonia?
4. There are many uses for electronic smell sensors. Think of a useful machine that would use a smell sensor. Draw a design for the machine showing the controls and how it would look.

How Smell Sensors Work

A smell sensor can be made from a quartz crystal with electrical connections and a special plastic coating. Quartz crystals are used in electronics because they can be made to vibrate at a precise frequency. A quartz crystal is what is used to control the speed of a processor in a PC. The frequency of vibration of the quartz crystal depends on its size, shape, stiffness and mass.

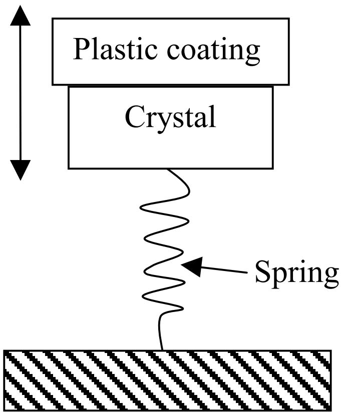




The plastic coating on the crystal absorbs some chemicals so increases the crystal's mass. The whole device is called a Quartz Crystal Microbalance (QCM).

A quartz crystal can be thought of as mass on a spring. The frequency of oscillation of a mass on a spring is given by the formula:

$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$



Where k is the stiffness of the system in Nm^{-1}
m is the mass of the system in kg
f is the frequency of the system in Hz

1) When the plastic coating absorbs a chemical the mass of the system increases. What happens to the frequency?

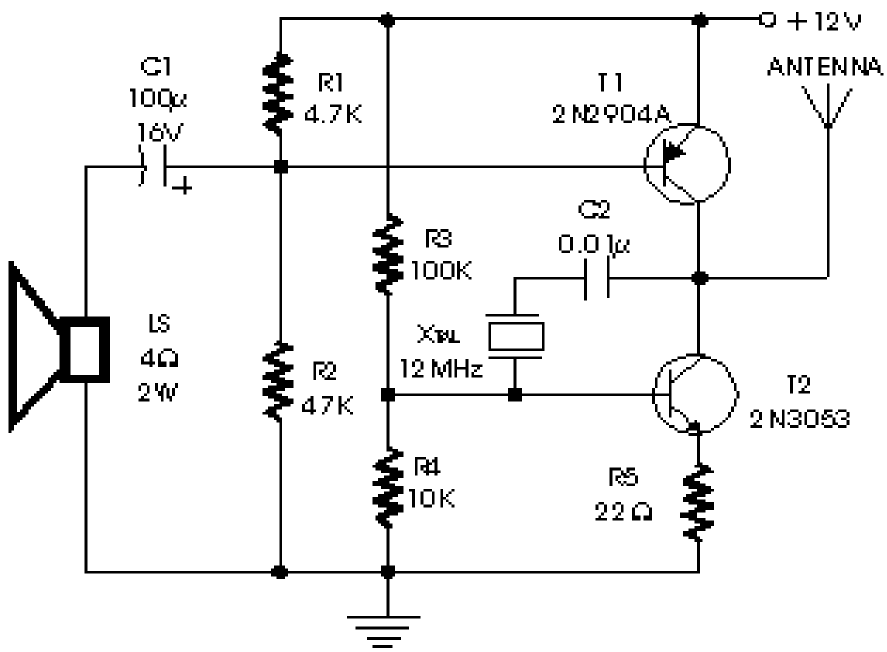
2) In a sensor the quartz crystal and plastic coating weighs 1.000mg (1.000×10^{-6}kg) and vibrates at a frequency of 50.0000MHz (5.0000×10^{7}Hz). What is the stiffness of the system?

3) The sensor now absorbs 0.20nanograms (2.0×10^{-10}kg) of chemicals.
   a) What is the new mass of the system?
   b) What is the frequency of the system now?

4) The frequency of the sensor is measured as 49.993MHz, what mass of chemicals have been absorbed?

5) The smallest change in frequency that can be detected is 50Hz. What is the smallest mass of absorbed chemicals that can be detected?

Short Wave AM Transmitter



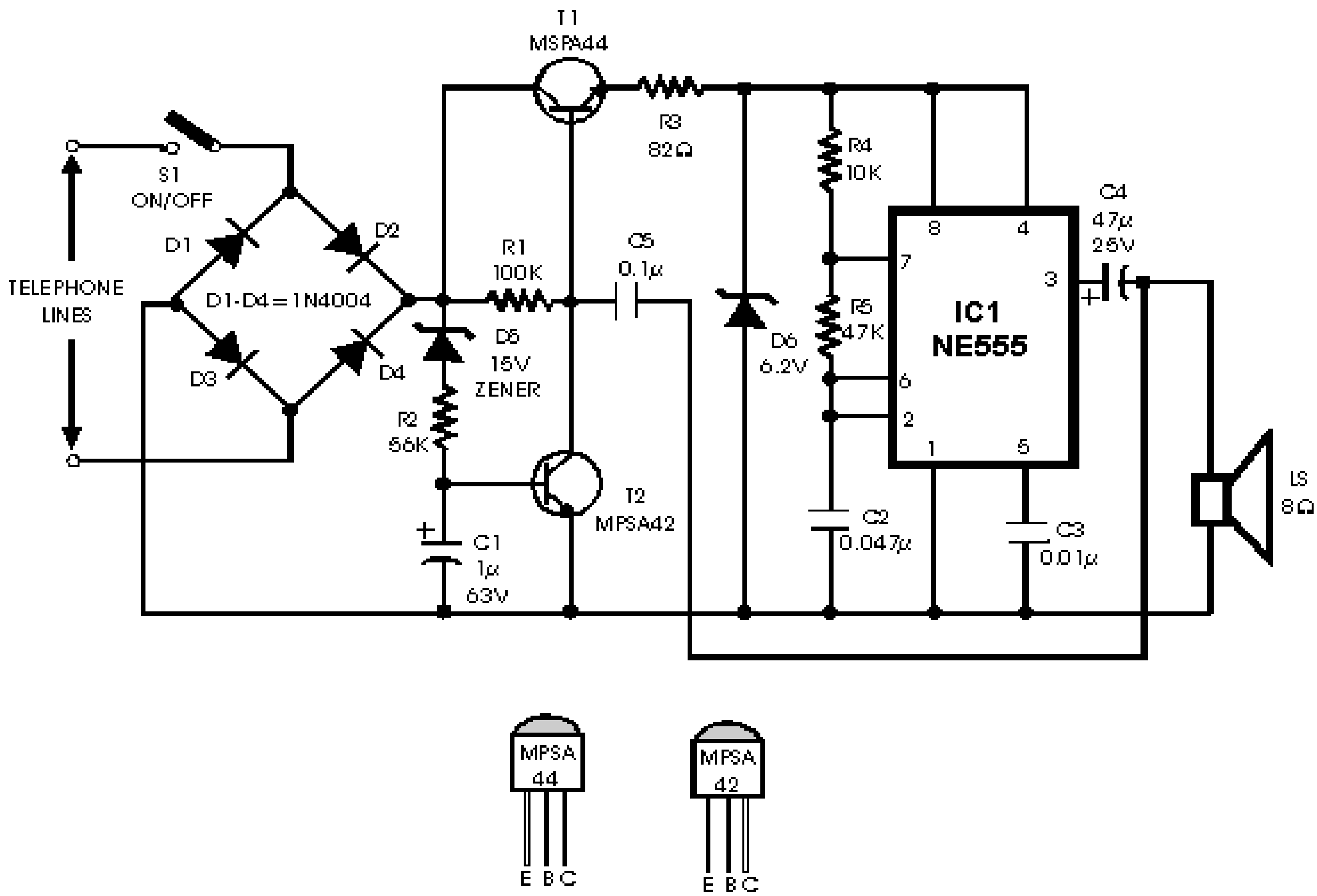
The main feature of this trans- mitter is that it is free from the LC (inductor, capacitor) tuned circuit and operates on a fixed frequency of 12 MHz which is extremely stable. An LC based tuned circuit is inherently unstable due to drift of resonant frequency on account of temperature and humidity variations. The circuit is very simple and uses only a few components. The figure shows the complete circuit diagram of the transmitter. Resistors R1 and R2 are used for DC biasing of transistor T1. The capacitor C1 provides coupling between the speaker and the base of transistor T1. Similarly, resistors R3, R4 and R5 provide DC bias to transistor T2. Resistor R5 also provides negative feedback which results in higher stability. The oscillator section is a combination of transistor T2, crystal Xtal, capacitor C2 and resistors R3, R4 and R5. The crystal is excited by a portion of energy from the collector of transistor T2 through the feedback capacitor C2. Thus the oscillator circuit generates the carrier frequency at its fundamental frequency of 12 MHz. Any crystal having the frequency in short wave range can be substituted in this circuit, although the operation was tested with a 12MHz crystal. Transistor T1 serves three functions:

* It provides the DC path for extending +Vcc supply to transistor T2.
* It amplifies the audio signals obtained from speaker.
* It injects the audio signal into the high frequency carrier signal for modulation.

The loudspeaker converts the voice message into the electrical signal which is amplified by transistor T1. This amplified audio signal modulates the carrier frequency generated by transistor T2. The amplitude modulated output is obtained at the collector of transistor T2 and is transmitted by a long wire antenna into space in the form of electromagnetic waves. The transmitted signals can be received

on any short wave receiver without distortion and noise. The range of this transmitter is 25 to 30 metres and can be extended further if the length of the antenna wire is suitably increased along with proper matching.

Watch-Dog for Telephones



PIN CONFIGURATION OF TRANSISTOR T1 AND T2
(FRONT VIEW)

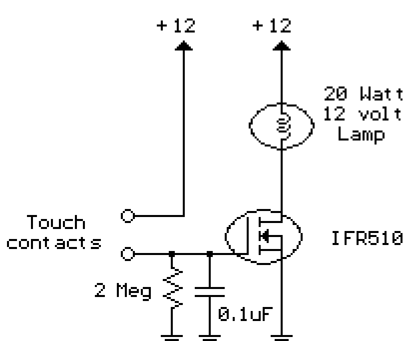
Most of the telephone security devices available in market are simple but quite expensive. These devices provide blinking or beeping type line-tap/misuse indications. Quite often they do not offer guaranteed protection against unauthorised operation. A very simple and uni- que circuit of a telephone watch-dog to safeguard subscriber telephone lines against any fraud is described here. This little circuit keeps continuous watch over the telephone lines and sounds an alarm in case of any misuse. In addition it transmits a loud tone through the telephone lines to prevent further misuse. When switch S1 is turned on, the normal (on-hook) telephone line voltage at the output of bridge-rectifier diodes D1 to D4 is approximately 48 volts, which being well above the break-down voltage of zener diode D5, the diode conducts. As a result transistor T2 gets forward biased. This effectively grounds the base of transistor T1 which is thus cut off and the remaining circuit does not get any

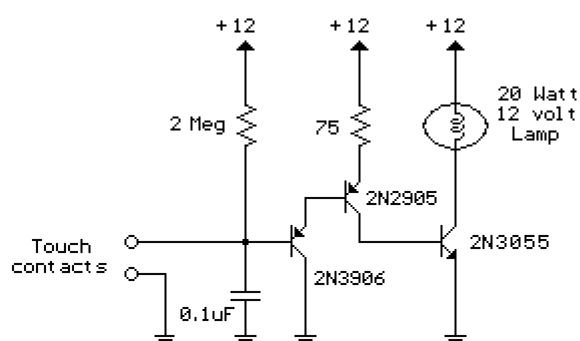
power supply. In this state, only a small (negligible) current is taken by the circuit, which will not affect the telephone line condition. However, when handset of any telephone connected to the telephone lines is lifted (off-hook), line voltage suddenly drops to about 10 volts. As a result, transistor T2 is switched off and transistor T1 gets forward biased via resistor R1. Now, the astablemultivibrator built around timer IC1 starts oscillating and the speaker starts sounding. Output of the astable multivibrator is also connected to the base of transistor T1 through capacitor C5. As a result, only a loud (and irritating) tone is heard in the ear-piece of the unauthorised telephone instrument. This circuit can be constructed on a veroboard using easily available low-cost components and it can be connected to any telephone line without the fear of malfunctioning. No extra power supply is required as it draws power from the telephone line for operation. Note: Please disconnect the gadget when you are yourself using the telephone as it cannot distinguish between authorised and unautho- rised operation

Touch Activated Light

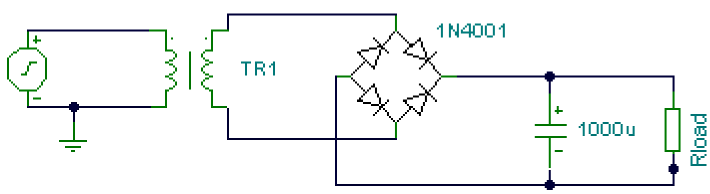
The circuit below lights a 20-watt lamp when the contacts are touched and the skin resistance is about 2 Megs or less. The circuit on the left uses a power MOSFET that turns on when the voltage between the source and gate is around 6 volts. The gate of the MOSFET draws no current so the voltage on the gate will be half the supply voltage or 6 volts when the resistance across the touch contacts is equal to the fixed resistance (2 Megs) between the source and gate.

The circuit on the right uses three bipolar transistors to accomplish the same result with the touch contact referenced to the negative or ground end of the supply. Since the base of a bipolar transistor draws current and the current gain is usually less than 200, three transistors are needed to raise the micro amp current level through the touch contacts to a couple amps needed by the light. For additional current, the lamp could be replaced with a 12 volt relay and diode across the coil.





Unregulated Power Supply



A basic full wave rectified power supply is shown below. The transformer is chosen according to the desired load. For example, if the load requires 12V at 1amp current, then a 12V, 1 amp rated transformer would do. However, when designing power supplies or most electronic circuits, you should always plan for a worst case scenario. With this in mind, for a load current of 1 amp a wise choice would be a transformer with a secondary current rating of 1.5 amp or even 2 amps. Allowing for a load of 50% higher than the needed value is a good rule of thumb. The primary winding is always matched to the value of the local electricity supply.

The A/D Easily Allows Many Unusual Applications

National Semiconductor
Application Note 233
September 1974

Accommodation of Arbitrary Analog Inputs

Two design features of the ADC0801 series of A/D converters provide for easy solutions to many system design problems. The combination of differential analog voltage inputs and a voltage reference input which can range from near zero to $5V_{DC}$ are key to these application advantages.

In many systems the analog signal which has to be converted does not range clear to ground (0.00 V_{DC}) nor does it reach up to the full supply or reference voltage value. This presents two problems: 1) a “zero-offset” provision is needed — and this may be volts, instead of the few millivolts which are usually provided; and 2) the “full scale” needs to be adjusted to accommodate this reduced span. (“Span” is the actual range of the analog input signal, from $V_{IN\ MIN}$ to $V_{IN\ MAX}$.) This is easily handled with the converter as shown in *Figure 1*.

Note that when the input signal, V_{IN}, equals $V_{IN\ MIN}$ the “differential input” to the A/D is zero volts and therefore a digital output code of zero is obtained. When V_{IN}equals $V_{IN\ MAX}$, the “differential input” to the A/D is equal to the “span” (for reference applications convenience, there is an internal gain of two to the voltage which is applied to pin 9, the $V_{REF}/2$ input), therefore the A/D will provide a digital full scale. In this way a wide range of analog input voltages can be easily accommodated.

An example of the usefulness of this feature is when operating with ratiometric transducers which do not output the complete supply voltage range. Some, for example, may output 15% of the supply voltage for a zero reading and 85% of the supply for a full scale reading. For this case, 15% of the supply should be applied to the $V_{IN(-)}$ pin and the $V_{REF}/2$ pin should be biased at one-half of the span, which is ½ (85%–15%) or 35% of the supply. This properly shifts the zero and adjusts the full scale for this application. The $V_{IN(-)}$ input can be provided by a resistive divider which is driven by the power supply voltage and the $V_{REF}/2$ pin should be driven by an op amp. This op amp can be a unity-gain voltage follower which also obtains an input voltage from a resistive divider. These can be combined as shown in *Figure 2*.

This application can allow obtaining the resolution of a greater than 8-bit A/D. For example, 9-bit performance with the 8-bit converter is possible if the span of the analog input voltage should only use one-half of the available 0V to 5V span. This would be a span of approximately 2.5V which could start anywhere over the range of 0V to $2.5V_{DC}$.

The RC network on the output of the op amp of *Figure 2* is used to isolate the transient displacement current demands of the $V_{REF}/2$ input from the op amp.

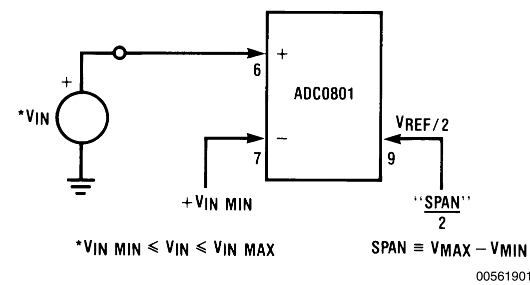


FIGURE 1. Providing Arbitrary Zero and Span Accommodation

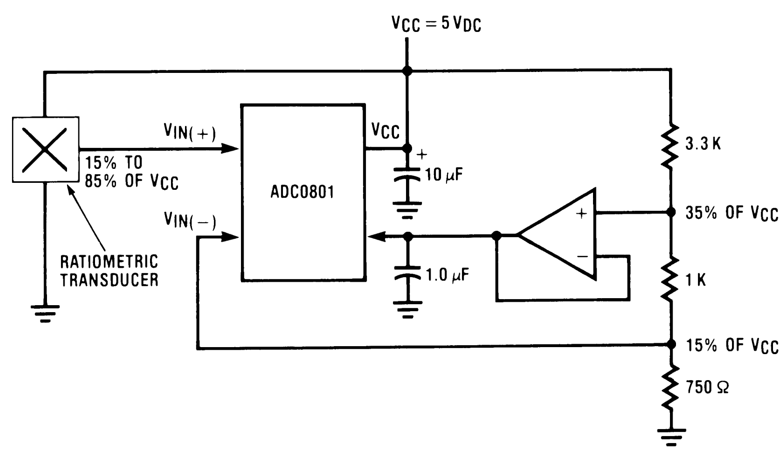


FIGURE 2. Operating with a Ratiometric Transducer which Outputs 15% to 85% of V_{CC}

Limits of $V_{REF}/2$ Voltage Magnitude

A question arises as to how small in value the span can be made. An ADC0801 part is shown in *Figure 3* where the $V_{REF}/2$ voltage is reduced in steps: from A), 2.5V (for a full scale reading of 5V); to B), 0.625V (for a full scale reading of 1.25V — this corresponds to the resolution of a 10-bit converter over this restricted range); to C), 0.15625V (for a full scale reading of 0.3125V — which corresponds to the resolution of a 12-bit converter). Note that at 12 bits the linearity error has increased to ½ LSB.

For these reduced reference applications the offset voltage of the A/D has to be adjusted as the voltage value of the LSB changes from 20 mV to 5 mV and finally to 1.25 mV as we go from A) to B) to C). This offset adjustment is easily combined with the setting of the $V_{IN\ MIN}$ value at the $V_{IN(-)}$ pin.

Operation with reduced $V_{REF}/2$ voltages increases the requirement for good initial tolerance of the reference voltage (or requires an adjustment) and also the allowed changes in the $V_{REF}/2$ voltage over temperature are reduced.

An interesting application of this reduced reference feature is to directly digitize the forward voltage drop of a silicon diode as a simple digital temperature sensor.

A 10-Bit Application

This analog flexibility can be used to increase the resolution of the 8-bit converter to 10 bits. The heart of the idea is shown in *Figure 4*. The two extra bits are provided by the 2-bit external DAC (resistor string) and the analog switch, SW1.

Note that the $V_{REF}/2$ pin of the converter is supplied with ⅛ V_{REF} so each of the four spans which are encoded will be:

$$2 \times \frac{1}{8} V_{REF} = \frac{1}{4} V_{REF}$$

In actual implementation of this circuit, the switch would be replaced by an analog multiplexer (such as the CD4066 quad bilateral switch) and a microprocessor would be programmed to do a binary search for the two MS bits. These two bits plus the 8 LSBs provided by the A/D give the 10-bit data. For a particular application, this basic idea can be simplified to a 1-bit ladder to cover a particular range of analog input voltages with increased resolution. Further, there may exit a *priori* knowledge by the CPU which could locate the analog signal to within the 1 or 2 MSBs without requiring a search algorithm.

A Microprocessor Controlled Voltage Comparator

In applications where set points (or “pick points”) are set up by analog voltages, the A/D can be used as a comparator to determine whether an analog input is greater than or less than a reference DC value. This is accomplished by simply grounding the $V_{REF}/2$ pin (to provide maximum resolution) and applying the reference DC value to the $V_{IN(-)}$ input. Now with the analog signal applied to the $V_{IN(+)}$input, an all zeros code will be output for $V_{IN(+)}$ less than the reference voltage and an all ones code for $V_{IN(+)}$ greater than the reference voltage. This reduces the computational loading of the CPU. Further, using analog switches, a single A/D can encode some analog input channels in the “normal” way and can provide this comparator operation, under microprocessor control, for other analog input channels.

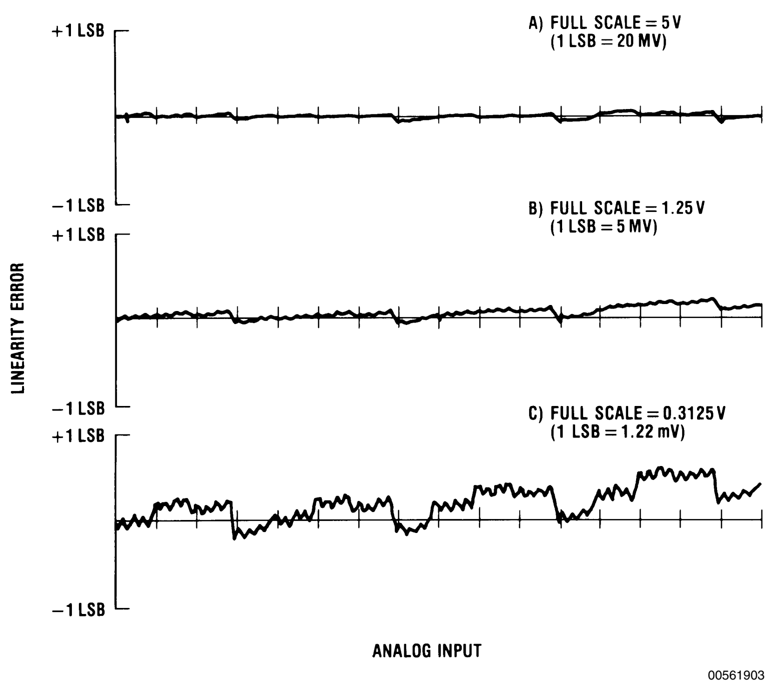


FIGURE 3. Linearity Error for Reduced Analog Input Spans

DACs Multiply and A/Ds Divide

Computation can be directly done with converter components to either increase the speed or reduce the loading on a CPU. It is rather well known that DACs multiply — and for this reason many are actually called "MDACs" to signify "multiplying DAC." An analog product voltage is provided as an output signal from a DAC for a hybrid pair of input signals — one is analog (the V_{REF} input) and the other is digital.

The A/D provides a digital quotient output for two analog input signals. The numerator or the dividend is the normal analog input voltage to the A/D and the denominator or the divisor is the V_{REF} input voltage.

High speed computation can be provided external to the CPU by either or both of these converter products. DACs are available which provide 4-quadrant multiplications (the MDACs and MICRO-DACs™), but A/Ds are usually limited to only one quadrant.

Combine Analog Self-Test with Your Digital Routines

A new innovation is the digital self-test and diagnostic routines which are being used in equipment. If an 8-bit A/D converter and an analog multiplexer are added, these testing routines can then check all power supply voltage levels and other set point values in the system. This is a major application area for the new generation converter products.

Control Temperature Coefficients with Converters

The performance of many systems can be improved if voltages within the system can be caused to change properly with changes in ambient temperature. This can be accomplished by making use of low cost 8-bit digital to analog converters (DACs) which are used to introduce a "dither" or small change about the normal operating values of DC power supplies or other voltages within the system. Now, a single measurement of the ambient temperature and one A/D converter with a MUX can be used by the microprocessor to establish proper voltage values for a given ambient temperature. This approach easily provides non-linear temperature compensation and generally reduces the cost and improves the performance of the complete system.

Save an Op Amp

In applications where an analog signal voltage which is to be converted may only range from, for example, $0V_{DC}$ to 500 mV_{DC}, an op amp with a closed-loop gain of 10 is required to allow making use of the full dynamic range ($0V_{DC}$ to $5V_{DC}$) of the A/D converter. An alternative circuit approach is shown in *Figure 5*. Here we, instead, attenuate the magnitude of the reference voltage by 10:1 and apply the 0 to 500 mV signal directly to the A/D converter. The $V_{IN(-)}$ input is now used for a V_{OS} adjust, and due to the "sampled-data" operation of the A/D there is essentially no V_{OS} drift with temperature changes.

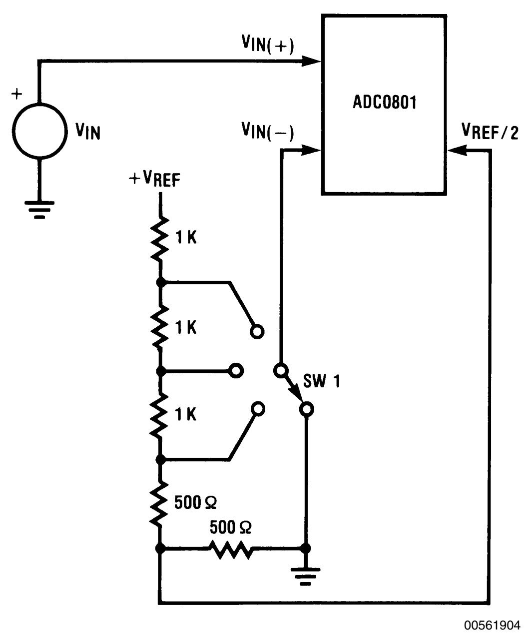


FIGURE 4. 10-Bit A/D Using the 8-Bit ADC801

Save an Op Amp (Continued)

As shown in *Figure 5*, all zeros will be output by the A/D for an input voltage (at the $V_{IN(+)}$ input) of $0V_{DC}$ and all ones will be output by the A/D for a $500mV_{DC}$ input signal. Operation of the A/D in this high sensitivity mode can be useful in many low cost system applications.

Digitizing a Current Flow

In system applications there are many requirements to monitor the current drawn by a PC card or a high current load device. This typically is done by sampling the load current flow with a small valued resistor. Unfortunately, it is usually desired that this resistor be placed in series with the V_{CC} line. The problem is to remove the large common-mode DC voltage, amplify the differential signal, and then present the ground referenced voltage to an A/D converter.

All of these functions can be handled by the A/D using the circuit shown in *Figure 6*. Here we are making use of the differential input feature and the common-mode rejection of the A/D to directly encode the voltage drop across the load current sampling resistor. An offset voltage adjustment is provided and the $V_{REF}/2$ voltage is reduced to 50 mV to accommodate the input voltage span of 100 mV. If desired, a multiplexer can be used to allow switching the $V_{IN(-)}$ input among many loads.

Conclusions

At first glance it may appear that the A/D converters were mainly designed for an easy digital interface to the microprocessor. This is true, but the analog interface has also been given attention in the design and a very useful converter product has resulted from this combination of features.

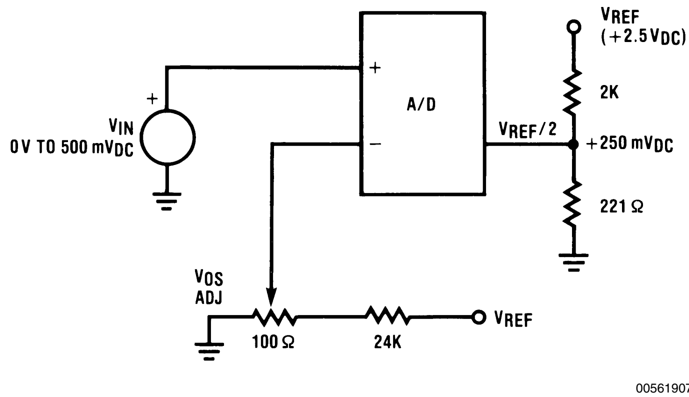


FIGURE 5. Directly Encoding a Low Level Signal

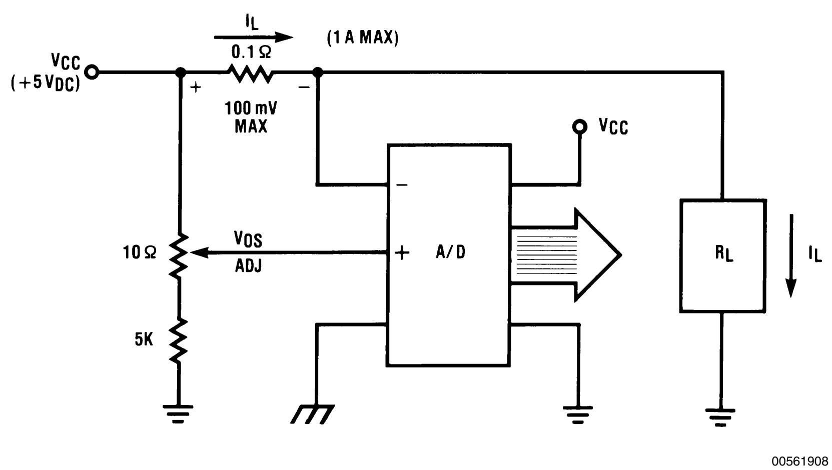


FIGURE 6. Digitizing a Current Flow

Notes

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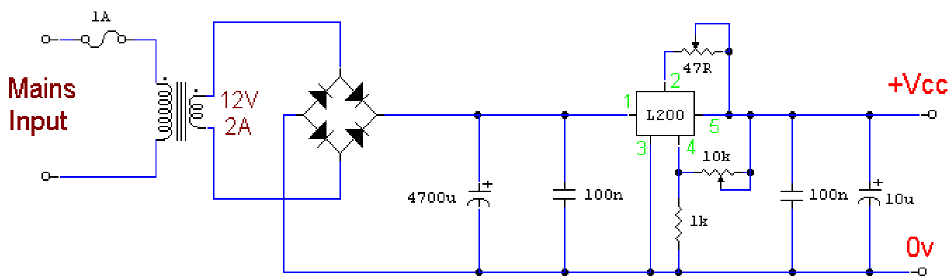
Variable Power Supply



Using the versatile L200 voltage regulator, this power supply has independent voltage and current limits. The mains transformer has a 12volt, 2 amp rated secondary, the primary winding should equal the electricity supply. The 10k control is adjusts voltage output from about 3 to 15 volts, and the 47 ohm control is the current limit. This is 10mA minimum and 2 amp maximum. Reaching the current limit will reduce the output voltage to zero.

WASHING MACHINE MOTOR CONTROLLER

S.C. DWIVEDI

SANTHOSH VASUDEVAN

Washing machines usually employ a single-phase motor. In semi-automatic washing machines, a purely mechanical switch controls the timing and direction of the motor. These switches are costly and wear out easily.

Here's a controller for single-phase motors of washing machines (Fig. 1) that efficiently replaces its mechanical equivalent. Basically, a single-phase motor requires a master timer, which decides the time for which the motor should keep rotating (washing time), and a spin direction controller, which stops the motor for 3 seconds after every 10 seconds and then resumes rotation in opposite direction.

The direction of rotation can be controlled as shown in Fig. 2. When switch S1 is in position A, coil L1 of the motor receives the current directly, whereas coil L2 receives the current with a phase shift due to capacitor C. So the rotor rotates in clockwise direction (see Fig. 2(a)). When switch S1 is in position B, the reverse happens and the rotor rotates in anti-clockwise direction (see Fig. 2(b)). Thus switch S1 can change the rotation direction.

The motor cannot be reversed instantly. It needs a brief pause between switching directions, or else it may get damaged. For this purpose, another spin direction control timer (IC2) is employed. It is realised with an IC 555. This timer gives an alternate 'on' and 'off' time duration of 10 seconds and 3 seconds, respectively. So after every l0 seconds of running (either in clockwise or anticlockwise direction), the motor stops for a brief duration of 3 seconds. The values of R3 and R4 are calculated accordingly.

The master timer is realised with monostable IC 555 (IC1) and its 'on' time is decided by the resistance of 1-mega-ohm potmeter VR. A 47-kilo-ohm resistor is added in series so that even when the VR knob is in zero resistance position, the net series resistance is not zero.

The on-off cycle in the master timer should

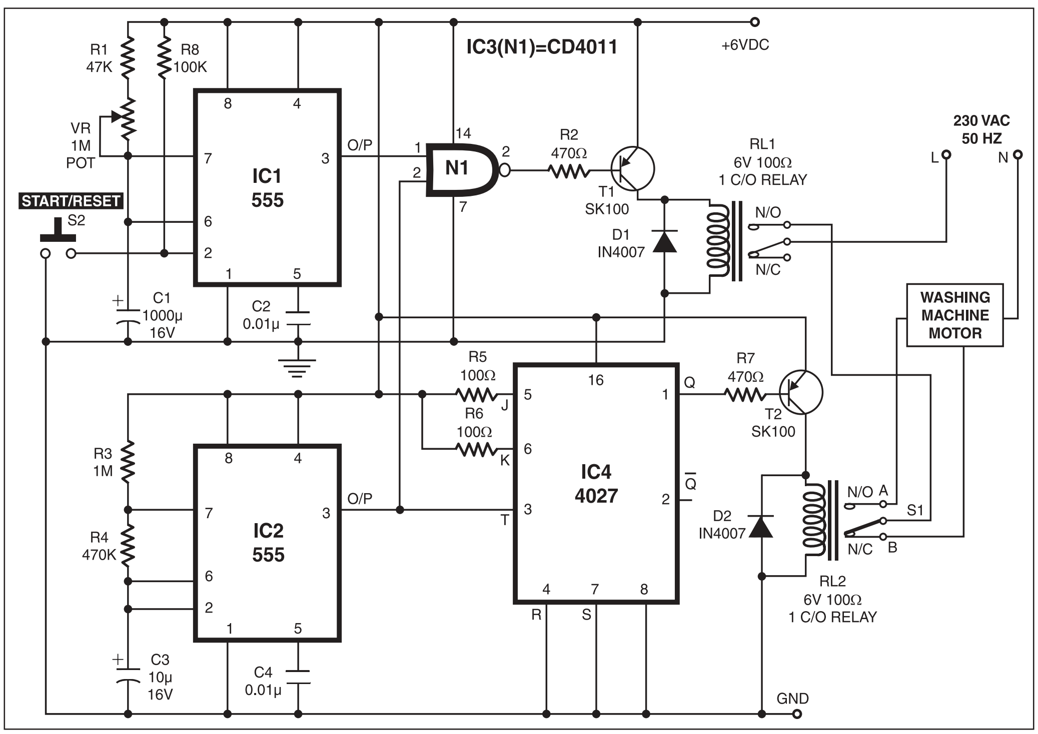


Fig. 1: Circuit diagram of washing machine motor controller

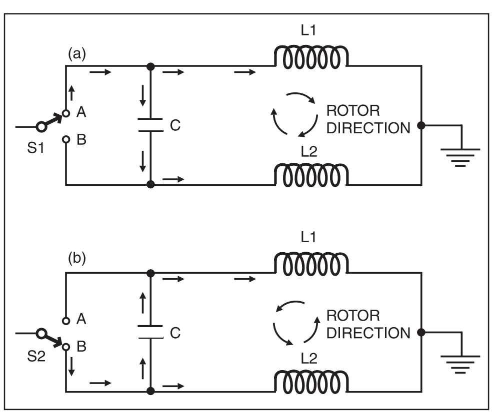


Fig. 2: Direction of motor

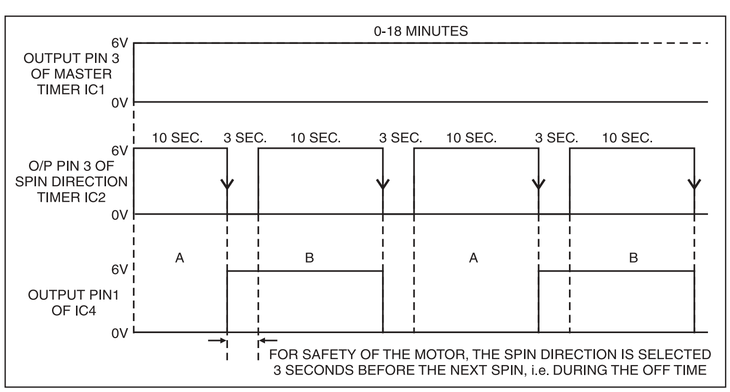


Fig. 3: Timing diagram for rotation of motor

go on only for the set time (here it is 18 minutes). Once the master timer goes off, the cycle should stop. To achieve this, the outputs of both the timers are connected to NAND gate N1 (IC3), which gives a low output only when both the timers are giving high outputs.The output pin 2 of N1 is connected to relay RL1 via pnp transistor T1, so the relay energises only when the output from NAND gate N1 is low. As the mains 220V line is taken through relay RL1, the motor turns off during the 3-second off period after the set time of 10 seconds is over. The graph is shown in Fig. 3.

During ‘on’ time of spin direction timer IC2, the output of negative-edge triggerd JK flip-flop at pin 2 goes low to energise relay RL2 and washing machine motor rotates in one direction. During the off time of IC2, the output of N1 goes high again to de-energise relay RL1, which cuts off the mains supply to RL2 and the motor stops rotating.

Floating point trouble may occur at trigger pin 2 of IC1. Resistor R8 overcomes this problem by holding pin 2 high.

TOUCH DIMMER

EFY TESTED — S.C. DWIVEDI

K. KRISHNA MURTY

By simply touching this touch dimmer you can increase the light intensity of incandescent lamps in three steps. The touch dimmer is built around 8-pin CMOS IC TT8486A/TT6061A specifically manufactured for touch dimmer applications.

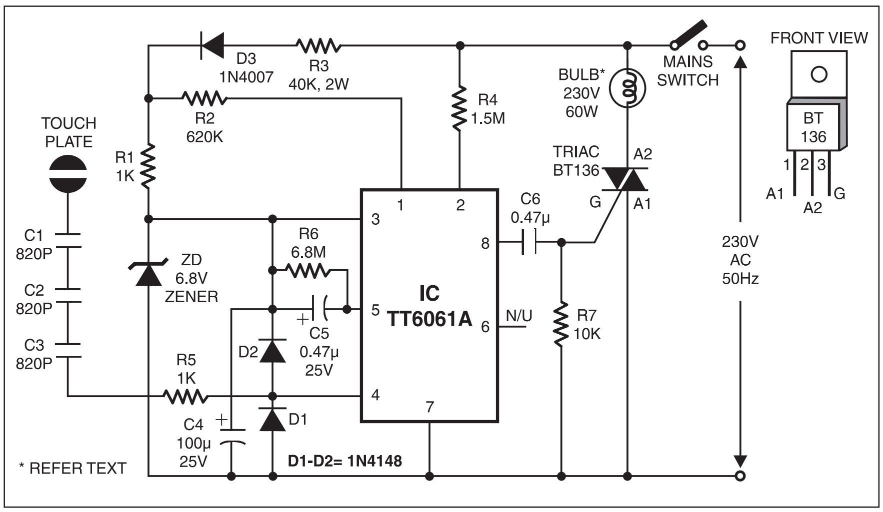
Initially, when mains switch is ‘on,’ the bulb is ‘off’. Now, if you touch the touch plate, the bulb glows dimly. On second touch, the bulb gives medium light. At the third touch, the bulb is driven fully. Another touch puts off the light.

Since the IC is highly sensitive, use a long wire to connect the IC to the touch sensor. The circuit uses minimum external components. For touch plate, you can use a simple copper plate of 1cm × 1cm or even the end of the lead wire. Touch plate is coupled to the touch detector through 820pF, 2kV capacitors C1, C2, and C3 connected in series. Internally IC TT6061A’s touch signal is connected to the counter/decoder via a resistor and clock input CK is connected to the counter/decoder via a frequency generator.

Line frequency signal is taken through R4 at pin 2 of IC TT6061A. At zero crossing, the triac (BT136) triggers to drive a 200W bulb.

The 6.8V power supply is taken directly from mains through resistors R1 and R3, diode D3, capacitor C4, and zener diode and fed to power-input pin 3 of the IC. Capacitors C1, C2, and C3 connected between touch input pin 4 and touch plate remove the shock potential from the touch plate, so do not replace these capacitors with a single capacitor or with a capacitor of a lower voltage rating. Mains potential exists in the circuit. Needless to say, it is dangerous to touch the circuit when mains is ‘on.’

Note. The IC had been procured by the author from SM Semiconductors, Santacruz (W), Mumbai.

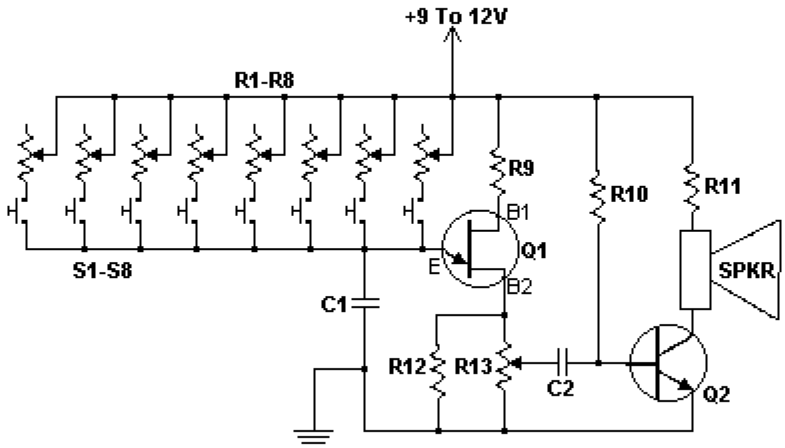


Pin Assignments of IC TT6061A

Pin No.	Pin name	Function description
1	CK	System clock input
2	FI	50Hz line frequency
3	V_{DD}	Power input pin for V_{DD}
4	TI	Touch input
5	CI	Sensor control input
6	NC	Not connected
7	V_{SS}	Power input pin for V_{SS}
8	AT	Angle-trigger output

Transistor Organ

This simple circuit can provide hours of enjoyment as you learn tunes, play duets or just make some really weird sounds by pushing all the buttons at once. You have probably seen this circuit before, it is fairly common. The best thing about the circuit is that you can tune each individual note, or go to a whole new octave by changing one capacitor (C1).



Part	Total Qty.	Description
R1-R8	8	250K Trim Or Regular Pot
R9, R12	2	100 Ohm 1/4 W Resistor
R10	1	10K 1/4 W Resistor
R11	1	220 Ohm 1/4 W Resistor
R13	1	5K Pot
C1	1	0.01uF Capacitor
C2	1	0.1uF Capacitor
Q1	1	2N4891 Unijunction Transistor
Q2	1	2N2222 Transistor
S1-S8	8	SPST Switch
SPKR	1	8 Ohm 2 W Speaker
MISC	1	Wire, Circuit Board, Knobs For Pots

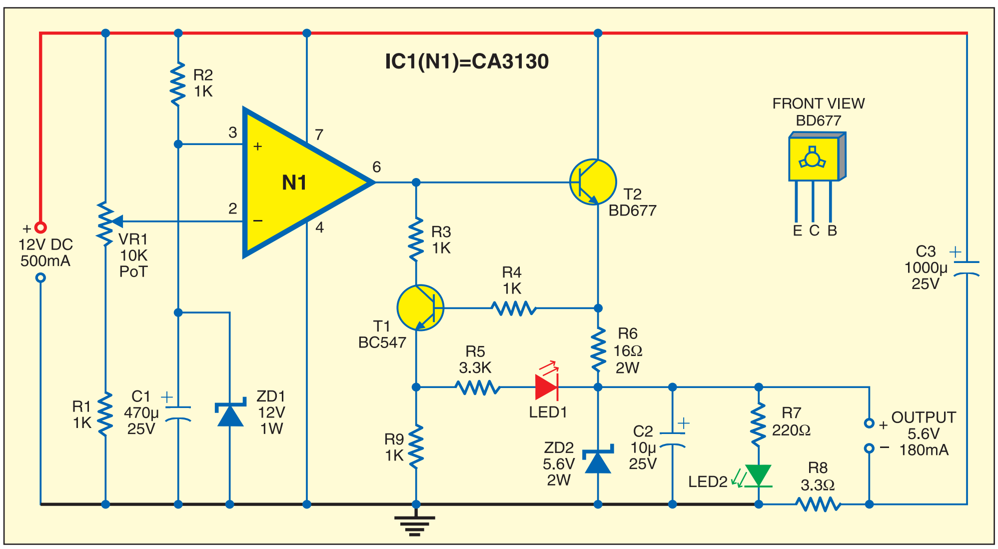
FRIENDLY CHARGER FOR MOBILE PHONES

■ D. MOHAN KUMAR

Most mobile chargers do not have current/voltage regulation or short-circuit protection. These chargers provide raw 6-12V DC for charging the battery pack. Most of the mobile phone battery packs have a rating of 3.6V, 650 mAh. For increasing the life of the battery, slow charging at low current is advisable. Six to ten hours of charging at 150-200mA current is a suitable option. This will prevent heating up of the battery and extend its life.

The circuit described here provides around 180mA current at 5.6V and protects the mobile phone from unexpected voltage fluctuations that develop on the mains line. So the charger can be left 'on' over night to replenish the battery charge.

The circuit protects the mobile phone as well as the charger by immediately disconnecting the output when it senses a voltage surge or a short circuit in the battery pack or connector. It can be called a 'middle man' between the existing charger and the mobile phone. It has features like voltage and current regulation, over-current protection, and high- and low-voltage cut-off. An added speciality of the circuit is that it incorporates a short delay of ten seconds to switch on when mains resumes following a power failure. This protects the mobile phone from instant voltage spikes.



The circuit is designed for use in conjunction with a 12V, 500mA adaptor (battery eliminator). Op-amp IC CA3130 is used as a voltage comparator. It is a BiMOS operational amplifier with MOSFET input and CMOS output. Inbuilt gate-protected p-channel MOSFETs are used in the input to provide very high input impedance. The output voltage can swing to either positive or negative (here, ground) side.

The inverting input (pin 2) of IC1 is provided with a variable voltage obtained through the wiper of potmeter VR1. The non-inverting input (pin 3) of IC1 is connected to 12V stabilised DC voltage developed across zener ZD1. This makes the output of IC1 high.

After a power resumption, capacitor C1 provides delay of a few seconds to charge to a potential higher than of inverting pin 2 of CA3130, thus the output of IC1 goes high only after the delay. In the case of a heavy power line surge, zener diode ZD1 (12V, 1W) will breakdown and short pin 3 of IC1 to ground and the output of IC1 drops to ground level. The output of IC1 is fed to the base of npn Darlington transistor BD677 (T2) for charging the battery. Transistor T2 conducts only when the output of IC1 is high. During conduction the emitter voltage of T2 is around 10V, which passes through R6 to restrict the charging current to around 180 mA. Zener diode ZD2 regulates the charging voltage to around 5.6V.

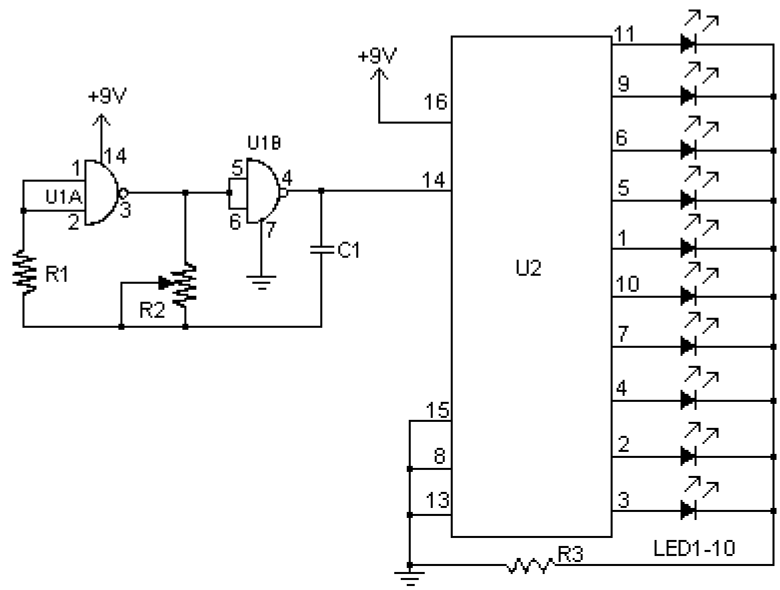
When a short-circuit occurs at the battery terminal, resistor R8 senses the over-current, allowing transistor T1 to conduct and light up LED1. Glowing of LED2 indicates the charging mode, while LED1 indicates short-circuit or over-current status.

The value of resistor R8 is important to get the desired current level to operate the cut-off. With the given value of R8 (3.3 ohms), it is 350 mA.

Charging current can also be changed by increasing or decreasing the value of R7 using the 'I=V/R' rule.

Construct the circuit on a common PCB and house in a small plastic case. Connect the circuit between the output lines of the charger and the input pins of the mobile phone with correct polarity. ●

LED Chaser



I don't know why, but people like blinking lights. You see LED chasers everywhere, in TV shows (Knight Rider), movies, and store windows. This schematic is my version of a simple 10 LED chaser.

Part List

R1 - 1 Meg 1/4W Resistor
R2 - 100K Pot
R3 - 1K 1/4W Resistor(220Ohm if using blue LEDs)
C1 - 0.1uF 16V Ceramic Disk Capacitor
U1 - 4011 CMOS NAND Gate
U2 - 4017 CMOS Counter
LED1-10 - LEDs Of Any Colour

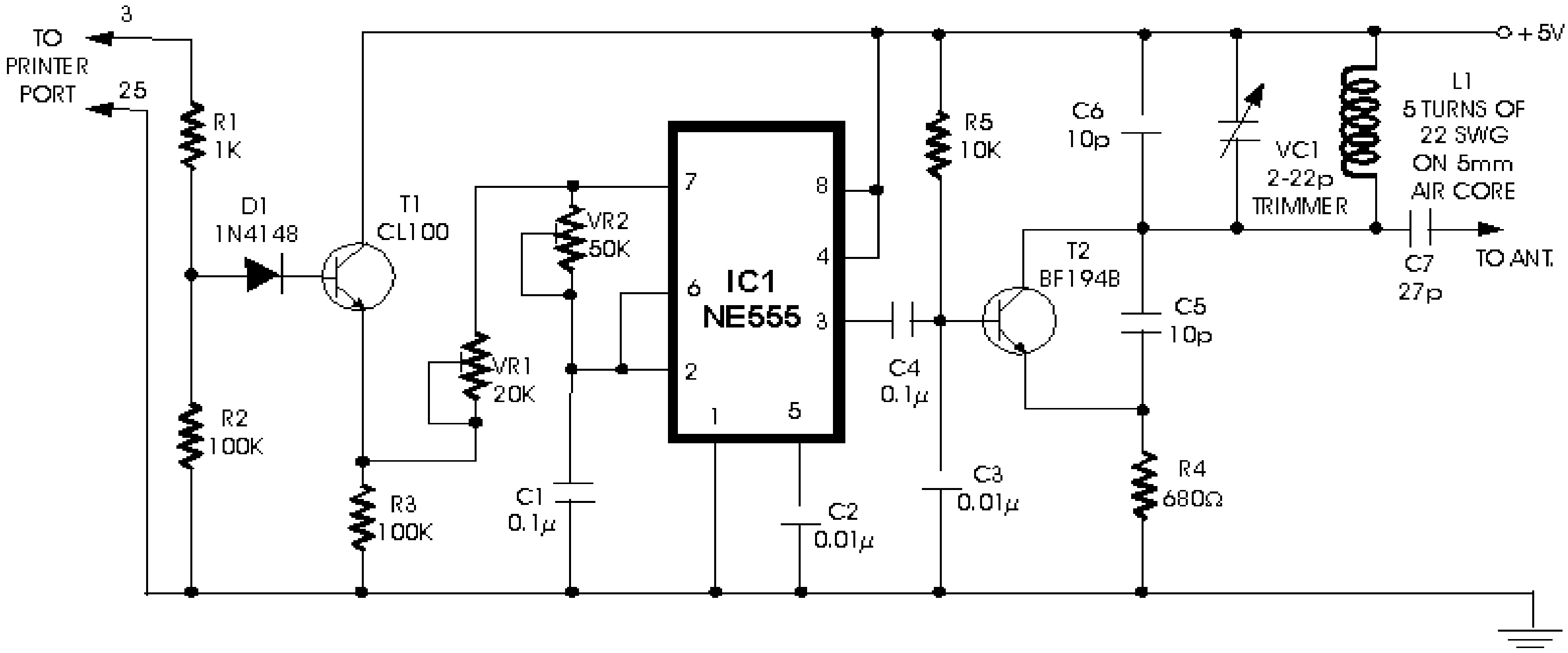
Notes:

1. Use R2 to adjust the "chase rate".

2. You may need to use a lower value resistor if you wish to use blue LEDs. Try 220 Ohm.

3. C1 may be replaced with a larger value for a slower "chase rate".

Computerised Morse code generator/transmitter



The circuit given here can be used to send telegraphic messages via computer. The message data entered through the computer keyboard is converted to corresponding Morse code and transmitted via the circuit attached to any IBM compatible computer's printer port. Morse code pulses from the computer appearing at pin 3 of the 25-pin parallel port are routed to the base of transistor T1 (CL100) which in turn switches on the audio frequency oscillator built around IC 555 for the duration of each pulse. The frequency of the oscillator can be varied by adjusting potmeters VR1 (20 kilo-ohm) and VR2 (50 kilo-ohm). The audio output from pin 3 of IC 555 is connected to an FM transmitter comprising transistor T2 (BF194B) and the associated components. The frequency of the transmitter can be changed with the help of trimmer capacitor VC1 or by changing the number of turns of coil L1.

The FM modulated signal is coupled to a short-wire antenna via capacitor C7. The signal can be received using any ready-made FM receiver tuned to the frequency of the transmitter. As stated earlier, this circuit is connected to the parallel port of the PC. Only pins 3 and 25 of the 'D' connector are used. Pin 3 corresponding to data bit D1 of port 378(hex) carries the Morse code data from the computer to the circuit while pin 25 serves as common ground. The circuit should be powered by 5 volts regulated power supply. It should be fixed inside a metal box to reduce interference.

The program, written in TURBO PASCAL 7.0, accepts the message via the keyboard, converts it to corresponding Morse code and sends the code to pin 3 of

the printer port. The Morse code of various characters appears under the function 'write(ch)' of the program wherein 'di' represents a short duration pulse and 'da' represents a long duration pulse. The program is interactive and permits variation of speed. The program can be modified to read and transmit the text files or one can even make a TSR (terminate and-stay-resident) program. It is hope that this circuit idea would prove to be of great value to the government's telecom department, defence services, coast guard, merchant navy and amateur radio operators as well as all those who make use of Morse code for message transmission.

A DC Motor Drive for a Dyno –

Microcontroller and Power Electronics

By

Jeffrey John Jordan

The School of Information Technology and Electrical Engineering

THE UNIVERSITY OF QUEENSLAND

Submitted for the degree of

Bachelor of Electrical Engineering (Honours)

In the division of Electrical & Electronic Engineering

OCTOBER 2001

13 Rylatt Street
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17 October 2001

The Dean
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Dear Professor Kaplan,

In accordance with the requirements of the degree of Bachelor of Engineering in the division of Electrical & Electronic Engineering, I present the following thesis entitled:

"A DC Motor Drive for a Dyno – Microcontroller and Power Electronics"

This work was completed under the guidance and supervision of Dr Geoff Walker.
I declare that the work contained in this document is my own, except as acknowledged in the text or references, and has not been previously submitted for a degree at the University of Queensland or at any other institution.

Yours faithfully,

Jeffrey Jordan

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Abstract

This thesis involves developing a DC motor drive for a dynamometer, which will be comprised of a microcontroller and power electronics. The DC shunt motor on the existing dynamometer would benefit from a dedicated DC motor drive based on a full bridge DC-DC converter. The power obtained from the dynamometer is to be recirculated to a DC bus meaning that only the losses of the test bench need to be supplied by a mains power supply. The motor drive for the dynamometer will also need to be capable of simulating road load conditions provided by the user for the motor under consideration. This will be achieved using the microcontroller to introduce a control loop for the dynamometer.

The development of this project involved modelling the dynamometer to help with the design of the controller that would be capable of controlling the torque of the dynamometer to the desired input level. This controller model was used to create coding for an Atmel microcontroller, which is required to run and interface with the power electronics, dynamometer and the user. The power electronics are based on a full bridge DC-DC converter constructed by David Finn for the Sunshark Solar Car and was slightly modified for the DC motor application.

A number of tests were carried out to ensure the functionality of the torque controller including simple tests for the A/D converter and PWM switching with the microcontroller, simulating conditions for the controller when connected to a motor and initial testing with the power electronics connected to a motor. These were followed by the final testing of the torque controller on a motor using open and closed loop control configurations.

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Chapter 1 Introduction

1.1 Thesis Overview

The topic of this thesis involves developing a DC motor drive for a dynamometer, which will be comprised of a microcontroller and power electronics. The dynamometer will be part of a test bench to be used to test the operation and performance of new motors and drives being introduced into the marketplace. When complete, the test bench would be made up of a test DC motor and motor driver, connected to the dynamometer and its associated driver made up of a torque controller and power electronics, a computer control system for simulating an electric vehicle driving and to perform data logging to evaluate the performance of the motor and drive under test, and a power bus to supply electricity to the test motor and to recirculate power produced from the dynamometer.

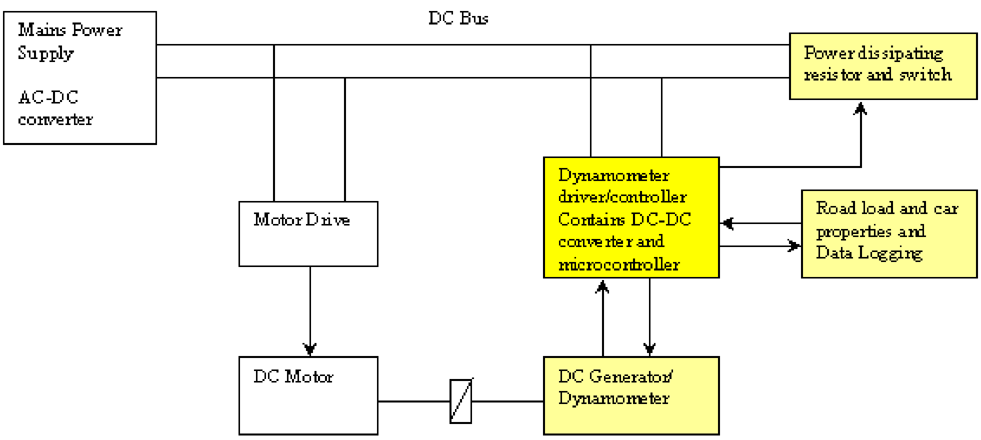


FIGURE 1.1: BASIC LAYOUT OF THE TEST BENCH.

Highlighted are the sections this thesis is concerned with. The resistor and switch on the DC bus will be required to dissipate power when both the motor and the generator are producing power, as is the case when the motor is braking.

The DC shunt motor on the existing dynamometer would benefit from a dedicated DC motor drive based on a full bridge DC-DC converter. The power obtained from the dynamometer is to be recirculated to the DC bus of the motor meaning that only the losses of the test bench need to be supplied by a mains power supply. The motor drive for the dynamometer will also need to be capable of simulating road load conditions provided by the user for the motor under consideration. This will be achieved using the microcontroller

to introduce a control loop for the dynamometer. The benefits of the complete system are that the performance of new motors and drives can be tested relatively easily saving time and, with the recirculation of power back to the DC bus, power can be saved as well.

The task of this project is to design the DC motor drive for the dynamometer along with the DC bus including AC mains power supply and over-voltage clamping. The mains supply will be fed through a rectifier to create a DC power supply (or alternatively, power supplied by battery packs). This will be used to power a motor of some sort and its driver. The motor will then be coupled to the DC dynamometer to turn the mechanical power from the motor back into electrical power. The power from the dynamometer will be fed back to the DC supply bus with the use of a full bridge DC-DC converter controlled by a microcontroller, which will be responsible for controlling the switching frequency of the converter. The motor drive will also be comprised of a torque control loop to vary the loading effect of the dynamometer on the motor being tested. The loading effects produced by the dynamometer will simulate a car as far as the test motor is concerned with the properties of mass, gradient and drag of a car being user-defined inputs to the dynamometer controller. With this system in place, only the losses from the test bed need to be supplied by the mains, saving power and money when testing new motors and drivers.

1.2 Areas of the Thesis

In this project, there are a number of different tasks that needed to be addressed to lead towards completion. These elements are discussed briefly in the following sections with more in depth information provided in later chapters as indicated.

1.2.1 Modelling and Simulation

The modelling and simulation of this thesis helped to plan the structure of the digital controller and generate expected outcomes of the project design. The program used was called Simulink, a sub program of the mathematical and simulation software Matlab. This software was the primarily used to provide simulation design and results for the motor

control loop for the dynamometer. Matlab also provided a method to convert the Simulink design into C code, using the Real Time Workshop component of Matlab, which was used to program the microcontroller. More details on the modelling and simulation designs, code and results are given in chapters 3 and 5.

1.2.2 Microcontroller

The microcontroller utilised for this thesis was needed to control the switching of the power electronics to vary the torque applied by the dynamometer to the test DC motor and be capable of future extensions and improvements. The Atmel AT90S8535 low-power CMOS 8-bit microcontroller was selected for this as it contains all of the necessary features required and is easy to program and understand. The features that where of most concern are its 10-bit A/D converter for current feedback and user-defined torque inputs, the 16-bit timer/counter with dual 8-, 9-, or 10-bit PWM mode for the Pulse Width Modulation produced for the power electronic switching and the full duplex Universal Asynchronous Receiver and Transmitter (UART) for serial communications with a PC. The Atmel will be discussed further in chapters 3 and 4.

1.2.3 Power Electronics

The power electronics for this thesis will be based on a full bridge DC-DC converter. A previously constructed converter used for the UQ's SunShark Solar Car, designed and built by David Finn (see Appendix A), will be slightly modified and form the motor controller for the dynamometer. The sections of the controller of interest for this thesis are the PAL chip socket (the Programmable Logic chip will be removed for an Atmel connector), the high voltage MOS gate driver IC to provide switching for the 3 phase bridge converter comprising of a number of MOSFETs, the current sensing resistors to provide feedback to the Atmel and the current sensing op-amps to provide a hardware trip to shut down the switching for currents that are too large to be handled by the motor controller. More details on the power electronics are given in chapters 2, 3 and 4.

1.2.4 DC Motor/Generator

The dynamometer to be used for this thesis is the ASEA DC motor/generator. The ASEA is a separately excited, 65kW, 3000rpm, 520V DC generator with a rated current of 125A. Although this project won't be reaching the maximum specifications of the ASEA due to the limitations of the power electronics, it is planned for future projects that these specifications will be met in years to come. DC motors/generators are discussed further in chapters 2, 3 and 4.

1.3 Thesis Structure

The structure of this thesis is set out into six sections.

- Chapter 1 gave an introduction to this thesis and a brief description of the different areas that make up the project.
- Chapter 2 will discuss the background and theory behind this thesis to give a better understanding of the topics faced during the project.
- Chapter 3 goes into in depth the design methods used to construct this thesis and discusses the different steps involved.
- Chapter 4 describes the implementation of the hardware and software used for the project.
- Chapter 5 reveals the results gained and gives an analysis of the outcome of the project, including simulation and practical data.
- Chapter 6 gives a summary and conclusions of the project and suggests future work that could be done to expand on the final design specified in this thesis.

Chapter 2 Review and Background

2.1 Literature Review

There have been many advances in the development of electric motors, and there is an increasing need for new control technology. Increased energy costs, public concern for unnecessary energy consumption and environmental impacts, and legislation requiring improved efficiency are among the key forces behind development of new motor controls [4]. The construction of this thesis project will mean a reduction of energy costs and consumption while providing a load simulator for testing the performance of new motors and their drivers.

The current technologies available for this thesis include an ASEA DC generator, a selection of microprocessors, a motor controller developed by David Finn and a number of methods for motor control. A previous thesis compiled by I. Stringer [1] covered the design, control and performance of a versatile, minimum energy regenerative road load simulator for laboratory use and contains the same dynamometer intended for this thesis. However, Stringer's road load simulator is vastly out of date being almost 20 years old, with the move to digital control and the use of computers being common practice these days.

The techniques involved with motor control, regeneration of mechanical power back to electrical power and the power electronics required to do so have been available for some time. DC motor control usually involves entering a desired speed/position to the controller, which will produce a control voltage for the power electronics to apply to the motor, with the actual speed/position being fed back to the controller (see Figure 2.1). Power electronics in the form of a DC-DC converter is required to provide control for the motor as well as regulating the power from the generator back to the main supply, the DC bus.

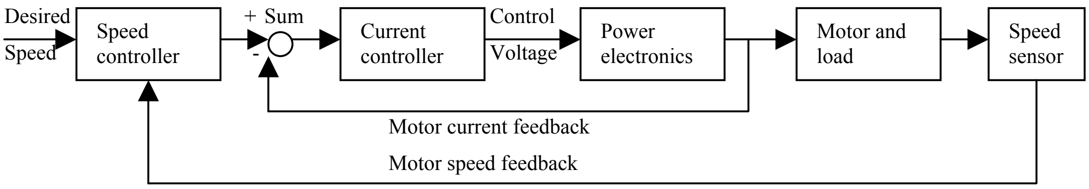


FIGURE 2.1: BLOCK DIAGRAM OF A CLOSED-LOOP DC MOTOR SPEED CONTROL.

However, this thesis will need to build on and modify these existing technologies to develop a motor controller that controls the torque of the dynamometer (hence creating a road load for the tested motor) and combine this with power electronics to produce a regenerative power loop for testing new motors and drivers. When completed, it will allow the testing of new motors to be used for the Sunshark and a hybrid electric car as well as being the basis of improved technology for larger power requirements. When completed, the test bench will become a relevant and useful piece of technology to be used by other studies at UQ.

2.2 DC Motor/Generator Theory

DC machines are one of the most common used machines for electromechanical energy conversion. Sen [5] describes the action of machines as being the conversion of energy from electrical to mechanical or vice versa results when a conductor moves in a magnetic field inducing voltage and a current-carrying conductor is placed in a magnetic field producing a mechanical force. These two effects occur simultaneously. In generating action, the rotating structure, the rotor, is driven by a prime mover of some sort. A voltage will be induced in the conductors that are rotating with the rotor. If an electrical load is connected to the winding formed by these conductors, a current will flow, delivering electrical power to the load. The current flowing through the conductor will interact with the magnetic field to produce a reaction torque, which will tend to oppose the torque applied by the prime mover [5, p121-2]. For motoring action, the process is reversed.

In an electric machine, the conductors are placed in slots of the stator, the part of the machine that doesn't move, or rotor and are interconnected to form windings. The two windings in a machine are the armature, with which voltage is induced, and the field that

current is passed to produce the primary source of flux. For a DC machine, the field winding is placed on the stator and the armature on the rotor [5, p125].

The dynamometer to be implemented for this thesis is a separately excited DC generator. Mohan [2] describes a separately excited DC motor as having the field winding connected to a separate source of DC power. The advantage of this type of DC machine over a permanent magnet DC motor are that the speed can be extended past its rated values and can offer greater flexibility. The technique to achieve this is known as field weakening [2, p381]. Figure 2.2 shows the equivalent circuit of a separately excited DC motor. This diagram shows that the terminal voltage, V_t, and the field flux, φ_f, can be controlled to yield the desired torque and speed. To maximise the motor torque capability, the field flux is kept at its rated value for speeds less than the rated speed for the motor. To obtain speeds beyond this, the terminal voltage is kept at its rated value and the field flux is decreased by decreasing the field current, I_f. The price to pay for the higher speeds is a reduction in torque since the maximum power into the motor is not allowed to exceed its rated value on a continuous basis. This region is also known as the constant power region for this reason [2, p381].

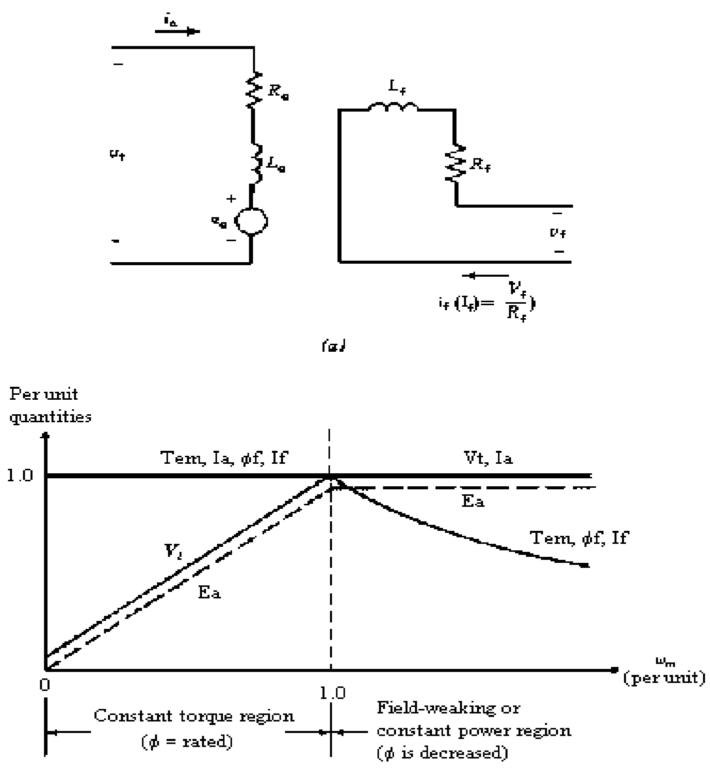


FIGURE 2.2: EQUIVALENT CIRCUIT OF A SEPARATELY EXCITED DC MOTOR AND ITS TORQUE-SPEED CURVE.

2.3 Motor Modelling and Simulation

To perform simulations of a system, an appropriate model needs to be established. For this thesis, the system contains a DC motor. Therefore, a model based on the motor specifications needs to be obtained. This is achieved by developing the open loop transfer function of a motor with the use of the system equations of a DC motor as given by Rashid [3]:

$$e_g = K_v I_f \omega \qquad \text{Equation 2.1}$$

$$v_t = R_a i_a + L_a \frac{di_a}{dt} + e_g = R_a i_a + L_a \frac{di_a}{dt} + K_v I_f \omega \qquad \text{Equation 2.2}$$

$$T_d = K_t I_f i_a = J \frac{d\omega}{dt} + B\omega + T_L \qquad \text{Equation 2.3}$$

where e_g is the induced back-emf

I_f is the field current

K_v is the voltage constant

ω is the rotor speed

v_t is the terminal voltage to the motor

R_a is the armature resistance

i_a is the armature current

L_a is the armature inductance

$K_t = K_v$ is the torque constant

T_d is the developed torque

J is the total equivalent damping

B is the total equivalent inertia

T_L is the load torque

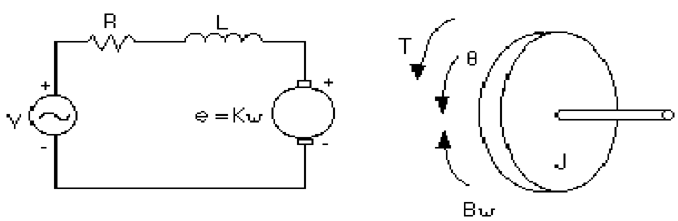


FIGURE 2.3: THE ELECTRIC CIRCUIT OF THE ARMATURE AND THE FREE BODY DIAGRAM OF THE ROTOR FOR A DC MOTOR.

From here, the system equations are changed into the s-domain using Laplace's transforms with zero initial conditions giving

$$V_t(s) = R_a I_a(s) + sL_a I_a(s) + K_v I_f \omega(s) \quad \text{Equation 2.4}$$

$$T_d(s) = K_t I_f I_a(s) = sJ\omega(s) + B\omega(s) + T_L(s) \quad \text{Equation 2.5}$$

Rearranging gives the equations for the electrical and mechanical components

$$I_a(s) = \frac{V_t(s) - K_v I_f \omega(s)}{R_a + sL_a} \quad \text{Equation 2.6}$$

$$\omega(s) = \frac{T_d(s) - T_L(s)}{B + sJ} \quad \text{Equation 2.7}$$

This provides the model the model for a DC motor as shown in Figure 2.4 to be used in simulations and design of the control system.

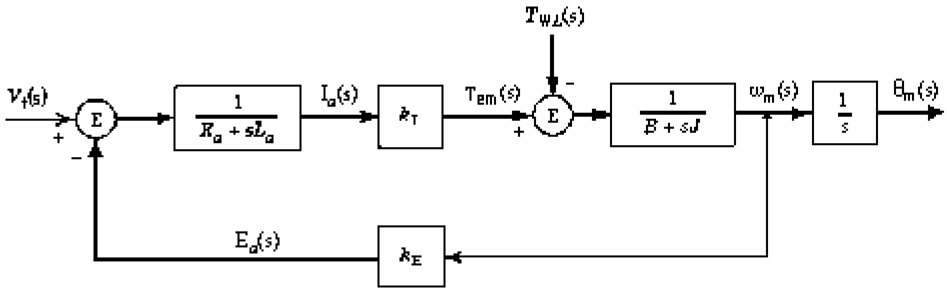


FIGURE 2.4: OPEN LOOP BLOCK DIAGRAM OF A SEPARATELY EXCITED DC MOTOR DRIVE.

The program used to complete the modelling and simulations with is called Simulink, a sub program of Matlab. The Matlab web page [8] describes Simulink as a software package for modelling, simulating and analysing dynamical systems. It supports linear and non-linear systems, modelled in continuous time, discrete time, or a hybrid of the two. For modelling, Simulink provides a graphical user interface (GUI) for building models as block diagrams, using click-and-drag mouse operations. Simulink includes a comprehensive block library of sinks, sources, linear and non-linear components, and connectors. After a model has been defined, it can be simulated, using a choice of integration methods, either from the Simulink menus or by entering commands in Matlab's command window. Using scopes and other display blocks, the simulation results can be viewed while the simulation is running. The simulation results can be put in the Matlab

workspace for post processing and visualisation. Simulink provided the perfect environment for developing motor models and controller designs for this thesis.

2.4 Control Systems Theory

The purpose of developing a control system is to enable stable and reliable control for any number of equipment, big or small. Control systems have numerous applications, from space shuttle lift offs and rocket control to fuel systems, robotics and motor control. Nise [6, p2] gives the four main reasons for building control systems as being for power amplification, remote control, convenience of input form, and compensation for disturbances.

A control system provides an output response for a given input. The input to the system is the desired response while the output is the actual response. This is known as the characteristic response of the system. The characteristic response is made up of three sections: the transient response, the steady-state response and the steady-state error [6, p10]. The transient response is the initial reaction to the input and is usually a gradual change compared to the instantaneous change of the input signal. After the physical system has settled, it reaches the steady-state response. This is where the output has attained an approximation of the desired response. The output of the system may not be exactly the same as the required input, meaning the there is same steady-state error. The error may be tolerable or it may need to be eliminated, depending on what the system is.

There are two types of control configurations, open loop and closed loop [6, p11-13]. Nise describes open loop systems as consisting of a subsystem called an input transducer that converts the input to that used by the controller, which then drives the process or plant. The disadvantage to open loop systems is that they are unable to correct the output if there are any disturbances or noise in the system or at the output. If this is a problem, a closed loop system may need to be used. Closed loop or feedback control systems are similar to open loop system except that they have a sensor of some sort that is used to feedback what the output is doing to the controller. In achieving this, the controller is able to compensate for any disturbances giving it greater control and accuracy over open loop systems.

Once the control system has been specified and the type of control has been decided on, the design and analysis is done. There are three major objectives of systems analysis and design: producing the desired transient response, reducing steady-state error, and achieving stability [6, p14-16]. The desired transient response depends on the system being designed, whether the output should match as close as possible to the input or if there needs to be a gradual change, and if the system is allowed to oscillate or not about the desired input. The steady-state error of a system usually is required to be as small as possible so as to make it reliable and accurate. Again, this is dependant on the system. Along with these two issues, stability is important to objective to be achieved. If a system is unstable, it could lead to self-destruction of the physical equipment, hence limits need to be in place to prevent this from happening.

The design process for control systems follows a six-step procedure [6, p21-26]:

1. Transform requirements into a physical system. This involves obtaining the requirements and design specifications.
2. Draw a functional block diagram. Here, the system is broken down into component parts and shows their interconnections, detailing the overall layout.
3. Create a schematic. The system is described in terms of its electrical, mechanical and electromechanical components.
4. Develop a mathematical model. Once the schematic has been completed, physical laws, such as Kirchoff's laws for electrical networks and Newton's laws for mechanical systems as well as some simplifying assumptions, are used to derive the mathematical model.
5. Reduce the block diagram. This involves converting the block diagram into a single block with a mathematical description that represents the system from its input to its output.
6. Analyse and design. When the block diagram has been reduced, the system is analysed to see if the response specifications and performance requirements can be met with simple adjustments of the system parameters. If the specifications haven't been met, the design may need additional hardware to achieve the desired performance.

As previously mentioned, a controller or compensator is needed to provide the drive for the process and provide compensation for disturbances. Compensators are used to improve the

transient response and the steady-state error characteristics of a system [6, p497]. The compensator implemented for this thesis is called a Proportional-plus-Integral (PI) controller. The basic operations of a PI controller are to increase the output of the controller if it has a positive input, decrease the output for a negative input or to keep the output constant if the controller receives zero input. The gains associated with the PI controller effect the response of the system. The proportional gain reduces rise time, increases the overshoot and reduces the steady-state error while the integral gain decreases the rise time, increases both the overshoot and settling time and eliminates the steady-state error. Therefore, a happy median needs to be found to achieve a reasonable output response.

2.5 DC Converters and Motor Controller Theory

DC-DC converters are extensively used in regulated switch-mode DC power supplies and in DC motor applications [2, p161]. Often the inputs to these converters are unregulated DC voltage that needs to be converted into a controlled DC output at a desired level. This is achieved by utilising one or more switches with the average output voltage controlled by the switches' on and off times. The method most commonly used to do this is called Pulse-Width Modulation (PWM) switching, which employs a constant frequency and varies the ratio between the on time and the switching time period. This is known as the duty ratio [2, p162].

The DC-DC converter most commonly found in DC motor drives is the full bridge converter (Figure 2.5). In this converter, the input is a fixed magnitude DC voltage and the output is a DC voltage that can be controlled in magnitude as well as in polarity [2, p188]. Therefore, the full bridge converter can operate in all four quadrants of the V-I plane (+V +I, +V -I, -V -I, -V +I) and can have power flow in either direction, making it ideal for DC motor/generator control situations.

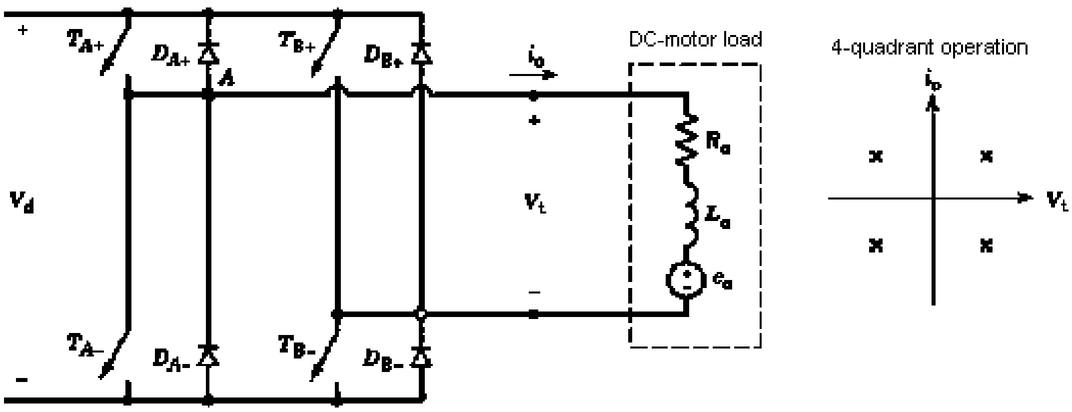


FIGURE 2.5: FULL BRIDGE DC-DC CONVERTER.

There are two types of switching strategies involving PWM to control the full bridge converter [2, p189-194]:

1. PWM with bipolar switching, where the diagonally opposite switches are treated as two switch pairs with each pair turned on and off simultaneously
2. PWM with unipolar voltage switching, where each of the inverter legs are controller independently of each other.

The second strategy results in a better output voltage waveform and better frequency response compared to the first method, since the effective switching frequency of the output voltage waveform is doubled and the ripple is reduced [2, p195].

The motor controller will be based on a 3-phase full bridge DC-DC converter previously designed and built by David Finn (see Appendix A). The hardware sections on this controller that is of particular importance are the high voltage MOS gate driver IC, the power MOSFETs, the current sensing resistors and the current sensing op-amps.

The MOSFETs used for the switching are the IRFP260 standard power MOSFETs. The main specifications for the MOSFETs as given on the datasheet [9] are a voltage rating of 200V, a maximum continuous current of 46A and an on resistance of 55mΩ. It features an international standard package, low on resistance, a rugged polysilicon gate cell structure, high commutating rating and fast switching times. Its main applications include switch-mode and resonant-mode power supplies, motor controls, uninterrupted power supplies and

DC choppers. Due to its low resistance and fast switching, the power losses involved in conduction and switching should be kept to a minimum.

The driver used to switch the MOSFETs is the IR2130 3-phase bridge driver. The IR2130, as stated on its datasheet [10], is a high voltage, high-speed power MOSFET and IGBT driver comprising of three independent high and low side referenced output channels. The logic inputs to the driver are compatible with CMOS or LSTTL outputs down to 2.5V. A ground-referenced operational amplifier provides an analogue feedback of bridge current via an external current sense resistor, which is also able to terminate all six outputs via a current trip function for over current detection. An open drain fault signal indicates if an over current or under voltage shutdown has occurred. The output drivers feature a high pulse current buffer stage designed for minimum driver cross-conduction, which ensures that the high and low side aren't switched on at the same time. The propagation delays are matched for all the channels to simplify use at high frequencies. The floating channels can also be used to drive N-channel power MOSFETs or IGBTs in the high side configuration that operates up to 600 volts.

The current sensing resistors on the motor controller board are required to provide a current measurement from the motor, which is to be fed back to the digital controller.
The voltage across the resistors will be measured, which will be proportional to the current, and read by the A/D converter on the Atmel. The resistors need to be low ohmic so as to not cause any significant effects to the power electronics and be rated for the power specifications given for the motor.

The current sensing op-amps are used as a hardware current trip or shut down to prevent the current from over-loading the power electronics and destroying the motor controller. The outputs from the op-amps are fed into the ITRIP pin on the IR2130, which will turn off all of the MOSFETs. There are two sets of op-amps, one for a soft shut down and the other for a hard shut down. The soft shut down tells the IR2130 to just ease off a little while the hard shut down tells it to completely turn off straight away.

Chapter 3 Design Method

The design of this thesis involved a number of separate sections, which were developed individually and combined to come up with the final project. Each part required research and understanding to enable the design to be carried out. The design methods used are discussed in the following sections.

3.1 Modelling

To come up with the best design, there needs to some amount of modelling or simulations to avoid aimless trial and error techniques with the actual equipment (the equipment being the power electronics and the DC generator). The other reason for developing a model of the power electronics and DC generator is so that the correct controller can be designed and allow for simulations to obtain the desired response.

To develop a good model of this thesis project, a number of specifications needed to be obtained and established. The specifications of the DC generator were obtained from Stringer's thesis [1], which included the power and speed, the voltage, current, resistance and inductance of the armature and field windings as well as the speed and torque constants and the rotor's moment of inertia. The other specifications that needed to be defined were the amount of voltage and current required for this thesis, which were set by the limitations of the power electronics being used and the scope of this thesis. All of the specifications are given in Table 3.1.

Specifications of the Dynamometer	
Power	65kW
Speed	3000rpm
Armature – voltage	520V
- current	125A (short term overload 367A)
- resistance	0.046Ω + 0.028Ω interpole resistance
- inductance	2.6mH (at 300Hz)
Field - voltage	220V (rated)
- current	1.1A (rated)
- resistance	112 Ω (measured cold), 133 Ω (measured hot)
- inductance	78H (measured)
- time constant	0.7s
Rotor moment of inertia	0.534kg.m^2
Scope for this thesis	
Voltage	140V
Current	125A

TABLE 3.1: SPECIFICATIONS OF THE DYNAMOMETER AND SCOPE FOR THIS THESIS.

With all of the required specifications of the generator and power electronics, a model of the generator was developed in Simulink. This was used to help design the controller that would be capable of controlling the torque of the generator to the desired input level. The generator was modelled using transfer functions of the electrical and mechanical characteristics derived from its armature resistance and inductance, rotor moment of inertia and friction as shown in Figure 3.1.

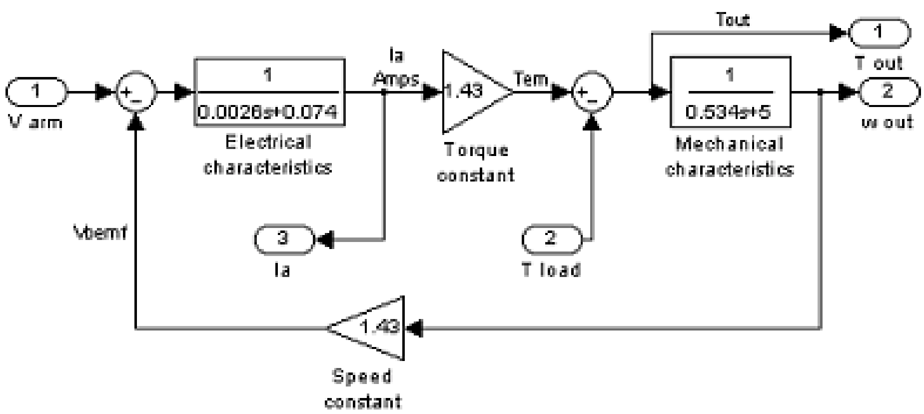


FIGURE 3.1: GENERATOR BLOCK DIAGRAM.

Figure 3.1 shows that the input to the generator is the armature voltage, V arm, which is summed with the back EMF, Vbemf. The result is fed into the electrical characteristics of

the generator producing the armature current, which is then converted to the produce torque through the torque constant. This can then be summed with any loading torque, giving the output torque, and fed into the mechanical characteristics of the generator. The result is the rotor speed given in radians per second and is fed back through the speed constant providing the back EMF. With this model, the controller was developed to acquire the desired output response from the generator.

3.2 Controller

The controller for the generator was developed in Simulink with the model given in the previous section. It needed to convert the desired torque input into a duty ratio for the power electronics. The controller was developed using discrete elements, as the controller was required to be digitalised for an easy transition to the Atmel with correct operation. Creating a digital controller for motor control allows for reasonably simple design and flexibility. The size and cost of a digital system is greatly reduced compared to implementation with an analogue control scheme and improves reliability and performance. A microcomputer control system is also capable of performing a number of other desirable tasks at the same time allowing for extra features to be added. These reasons are why a microprocessor-controlled drive has become the norm, making analogue control become almost obsolete [3, p.534-5].

The designed controller block diagram is shown in Figure 3.2. The input is a torque value from the user that gets converted to a current and is limited to a set maximum value. This produces the desired current for the generator. This current is summed with the actual current flowing through the armature and is sent through to a PI controller. The values of the gains set to achieve a desirable output response. To prevent the output from exceeding specified levels, the integrator is limited to avoid integral windup. The output from the PI section produces the desired armature voltage, which is then limited to 140V and converted to a duty ratio to be used to control the switching for the motor controller. The current, I_a, is read from the motor controller and is used in a feedback loop for the controller to be compared with the desired current.

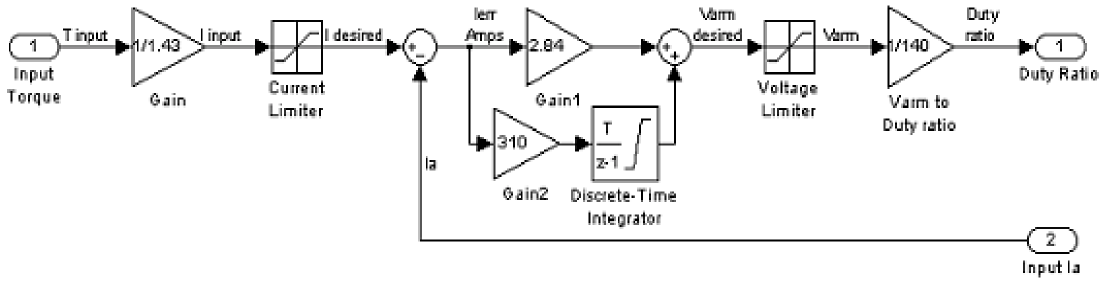


FIGURE 3.2: CONTROLLER BLOCK DIAGRAM DESIGNED WITH SIMULINK.

The simulation results of the controller with the model of the generator are discussed in Chapter 5. They show the output torque response when a step input is applied at the input of the controller. The results gained from the simulations gives an idea, in theory, of what should happen when this controller design is applied to the hardware. Simulations also help to prevent pure theory drifting away from reality.

Once the controller design was finalised in Simulink, the block diagram of the controller was converted to coding, in C, using Matlab's Real-Time Workshop that is able to generate optimised, portable, and customisable code from Simulink models. The important sections of the generated code was cut and modified so that it could be utilised with the Atmel.

The Atmel to be used as the controller needed to be able to handle all of the required inputs and outputs of the model developed in Simulink. These include the desired torque, the duty ratio output of the controller and the current feedback loop. The torque and the current are given as a voltage proportional to the actual values, therefore requiring an analogue-to-digital converter (ADC). The torque could also be read in using serial communications from a PC, requiring the use of a transmit and receive connection (UART). The power electronics requires the duty ratio to be in the form of a PWM signal to perform the switching of the MOSFETs. This means that the Atmel needs to be capable of producing PWM. The Atmel chosen to do all of the mentioned tasks is the AT90S8535 8-bit microcontroller. Details on the Atmel are given in Chapter 4.

The current feedback and PWM signals need to be sent to and from the power electronics through a connector board. This board is designed to fit into the socket on SunShark Motor controller given in Appendix A. The design and implementation of the connector board are given later in Chapter 4.

3.3 Power Electronics and Motor

The power electronics for this thesis is based on a DC/DC converter for the SunShark, and hence doesn't need a great deal of changing. The implementation, on the other hand, is different to its initial design purpose. The major items that need to be addressed with the power electronics involve the power specifications, power losses and heat sinking, how the PWM and the current feedback operates, and the output to the dynamometer.

3.3.1 Power Specifications

The power specifications for this thesis are 140V and 125A. The 140V was selected as a reasonable value for the MOSFETs to switch, since their maximum rated voltage is 200V. The design was limited to 125A maximum due to the ratings of the current sensing resistors. Since each of the 4 resistors have a rated power of 5W and are connected in parallel to each other, the current works out as follows

$$P = I^2 R$$

$$I = \sqrt{\frac{P}{R}} = \sqrt{\frac{5}{0.005/4}} = 31.6A\ (each\ resistor) \qquad \text{Equation 3.1}$$

$$I_{total} = 31.6 \times 4 \approx 125A$$

3.3.2 Power Losses

The power losses involved with the power electronics are primarily due to the MOSFETs. These losses come in the form of conduction losses and switching losses. Conduction losses occur when the MOSFET is on and is caused by the on resistance. These losses are calculated with the equation

$$P_{cond} = I_o^2 R_{on} \frac{t_{on}}{T_s} \qquad \text{Equation 3.2}$$

where I_o is the current

R_{on} is the on resistance

t_{on} is the on time

T_s is the switching period

The switching losses arise as the MOSFETs are switching between the on state to the off state and vice versa and are due to the fact that MOSFETs are not ideal in that they take time to switch on and off. Switching losses are calculated with the equation

$$P_{sw} = \frac{1}{2} V_d I_o f_s \left(t_{c(on)} + t_{c(off)} \right) \qquad \text{Equation 3.3}$$

where V_d is the input voltage

f_s is the switching frequency

$t_{c(on)}$ and $t_{c(off)}$ are the crossover times between the on and off states

Another important power loss involved with the switches in bridge converters (Figure 2.5) is shoot through losses, which occurs when both switches of a leg are on. This short circuits the converter and must be prevented.

3.3.3 Heat Sinking

With the power losses occurring with the MOSFETs, heat sinking is required to prevent them from over heating and failing at high currents. When a section of material has a temperature difference across it, there is a net flow of energy from the higher to the lower temperature end [2, p731]. The power from this energy flow is given by

$$P_{cond} = \frac{\lambda A \Delta T}{d} \qquad \text{Equation 3.4}$$

where $\Delta T = T_2 - T_1$, A is the cross-sectional area, d is the length, and λ is the thermal conductivity.

The thermal resistance of a material is given by

$$R_{\theta,cond} = \frac{\Delta T}{P_{cond}} = \frac{d}{\lambda A} \qquad \text{Equation 3.5}$$

In multi-layered materials, there are usually a number of different thermal conductivities, areas and thicknesses for the heat conduction path to flow through. Therefore, the total thermal resistance from the junction of the device to the ambient (ja) is

$$R_{\theta ja} = R_{\theta jc} + R_{\theta cs} + R_{\theta sa} \qquad \text{Equation 3.6}$$

The resulting junction temperature, with a power dissipation of P_d, is given by

$$T_j = P_d \left(R_{\theta jc} + R_{\theta cs} + R_{\theta sa} \right) + T_a \qquad \text{Equation 3.7}$$

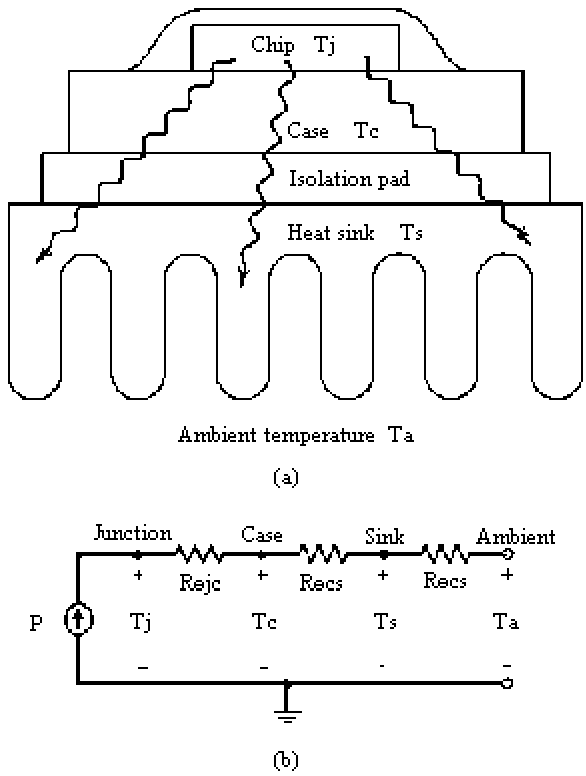


FIGURE 3.3: A HEAT SINK AND AN EQUIVALENT CIRCUIT BASED ON THERMAL RESISTANCES.

3.3.4 PWM and Current Feedback

The PWM input to the motor controller was through a programmable chip, which would perform logic operations with a number of other inputs to produce the signals for the IR2130 driver. However, this logic chip has been replaced by a connection to the Atmel. Therefore, the Atmel is responsible for creating the required PWM signals along with any other operations. The driver chip has capabilities of switching three phases, two of which will control the dynamometer and the third for field weakening, each supplied by the Atmel. For every phase, there is two outputs for the high and low sides, both need input signals that are opposite of each other, meaning that one is the invert of the other. This ensures that while either the high or low output is high, the other is low. The switching scheme and the inversion used for the different phases is discussed in Chapter 4.

The current feedback is done using sensing resistors and an amplifier. The resistors are low ohmic 5mΩ, to reduce the power losses, with a power rating of 5W, capable of withstanding the current being used by the motor. Because of the low resistance, the

voltage across them will be small, in the range of tens of milli-volts. This is too small for the Atmel's A/D converter to sense with any accuracy and requires amplification to be of any use. Therefore, the voltage is improved with an Instrumentation Amplifier, as described in the next chapter.

3.3.5 Output to the Dynamometer

To make sure that the output of the power electronics has good voltage regulation and efficiency, and has exactly half the applied voltage of the two input phases, an auto transformer was required between the two phases to the dynamometer (Figure 3.4).

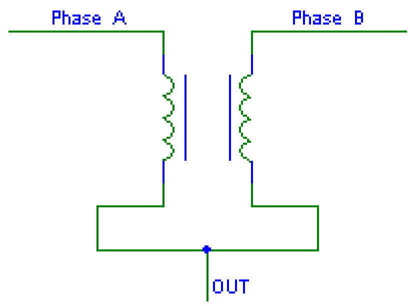


FIGURE 3.4: CONFIGURATION OF THE AUTO TRANSFORMER.

An auto transformer is a transformer that has an electrical connection between its input and output voltages with the primary and secondary windings sharing common turns. This ensures that the output voltage is always half of the input. The design of a small, natural convention cooled transformer used for this thesis is described here. The design required information on the primary voltage and current in addition to the frequency. The number of turns (N_1), area of the core (A_{core}) and the flux density (B_{max}) can be determined from the equation

$$N_1 = \frac{V_1}{4fA_{core}B_{\max}} \qquad \text{Equation 3.8}$$

This establishes the core size, shape and material need for a transformer. This information, along with the copper wire winding thickness for the desired current, gave the design of the auto transformer for the power electronics to the dynamometer.

3.3.6 Dynamometer

The ASEA DC dynamometer, as previously mentioned, is rated at 65kW, 3000rpm, 520V and 125A. For this thesis, the scope is for only 140V and 125A. This means that the generator will be able to run at its maximum torque, but at reduced speeds.

To act as a road load simulator, there are a number of factors contributing to the amount of torque that is required for motion of a car. There are four elements that describes the motion, each being unique to a particular vehicle:

- Inertia
- Aerodynamic Drag
- Rolling Drag
- Gradients

These give the amount of torque required to simulate a car driving under different conditions.

Chapter 4 Implementation

4.1 Software

4.1.1 About the Controlling Unit

The controlling unit utilised for this thesis is the Atmel AT90S8535 low-power CMOS 8-bit microcontroller (see Appendix C). The function capabilities of this Atmel are described here as stated in its datasheet [11]. By executing powerful instructions in a single clock cycle, the AT90S8535 achieves throughputs approaching 1 MIPS per MHz allowing designs to optimise power consumption versus processing speed. The AT90S8535 provides a number of features including 8K bytes of In-System Programmable Flash, 512 bytes of EEPROM, 512 bytes of SRAM, 32 general purpose I/O lines, 32 general purpose working registers, a real time clock, three flexible timer/counters with compare modes, internal and external interrupts, a programmable serial UART, 8-channel 10-bit A/D converters, a programmable Watchdog Timer with internal oscillator, a SPI serial port and three software selectable power saving modes. This device is manufactured using Atmel's high-density non-volatile memory technology. The on-chip ISP Flash allows the program memory to be reprogrammed in-system through an SPI serial interface or by a conventional non-volatile memory programmer. By combining an 8-bit RISC CPU with In-System Programmable Flash on a monolithic chip, the Atmel AT90S8535 is a powerful microcontroller that provides a highly flexible and cost efficient solution to many embedded control applications. The AT90S8535 is supported with a full suite of program and system development tolls including C compilers, macro assemblers, program debugger/simulators, in-circuit emulators and evaluation kits.

The features that have been concentrated on for this thesis are its:

- 10-bit successive approximation Analogue to Digital Converter [11]. The ADC is connected to an 8-channel analogue multiplexer and contains a sample and hold amplifier that ensures the input voltage to the ADC is held at a constant level during conversion. The ADC can operate in two modes – Single Conversion and

Free Run Mode. In Single Conversion Mode, the user initiates each conversion while Free Run Mode has the ADC constantly sampling and updating the ADC Data Register. The former is applied for this thesis. Each conversion takes between 65 and 260us, except for the first one that takes twice as long to initialise the ADC. This allows for reasonably fast sampling and response time for the controller program. The ADC is capable of a rail-to-rail input range allowing for voltages up to the Atmel supply to be sampled. With the 10-bit precision, the ADC has a resolution of around 5mV over a 5V range.

- 8- and 16-bit Timer/Counters [11]. The Atmel AT90S8535 contains three general-purpose Timer/Counters – two 8-bit and one 16-bit. The 16-bit Timer/Counter1 features both a high resolution and high accuracy usage with lower prescaling opportunities or low speed and exact timing functions with high prescaling. The Timer/Counter1 supports two Output Compare functions that include optional clearing of the counter on compare match A, and actions on the Output Compare pins on both compare matches. Of particular importance to this thesis is that Timer/Counter1 can be used as an 8, 9 or 10-bit Pulse Width Modulator. In this mode the counter and the compare registers serve as a dual glitch-free stand-alone PWM with centred pulses. Timer/Counter1 acts as an up/down counter, counting from zero to some predetermined value, where it turns and counts down again to zero before repeating the cycle. When the counter matches with the value in the compare registers, the output pins are set or cleared accordingly, producing the PWM signals. All of the PWM signals come out of the Atmel inverted, since the MOSFET driver chip inputs for the switching signals are inverted. The two Output Compare functions are used to control Phase A and B of the power electronics, and are switched 180 degrees out of phase of each other producing a multilevel switching scheme to control the input to the dynamometer. This switching scheme will be discussed further in the Hardware Implementation. The 8-bit Timer/Counter2 works similarly to Timer/Counter1 and is employed to control the field of the dynamometer to allow for field weakening.
- Full duplex Universal Asynchronous Receiver and Transmitter (UART) [11]. The UART's main features include a baud rate generator that can generate a large number of baud rates, high baud rates at low XTAL frequencies, 8 or 9 bits data, noise filtering, overrun detection, framing error detection, false start bit detection, three separate interrupts, and buffered transmit and receive. The UART allows

serial communications to occur between the Atmel and a PC so that the desired torque inputs can be set, thus allowing for a number of road load conditions to be simulated with the dynamometer. It has, however, been decided at this stage that the torque input would be supplied through the ADC using a potentiometer. The UART has been setup to allow easy design for future development of this thesis.

4.1.2 Programming Review

The programming that was applied to the Atmel was coded in C using a C-Compiler called Code Vision, which converted the code into assembly for the Atmel. The flowchart for the coding is shown in Figure 4.1 and the program listing is given in Appendix C.

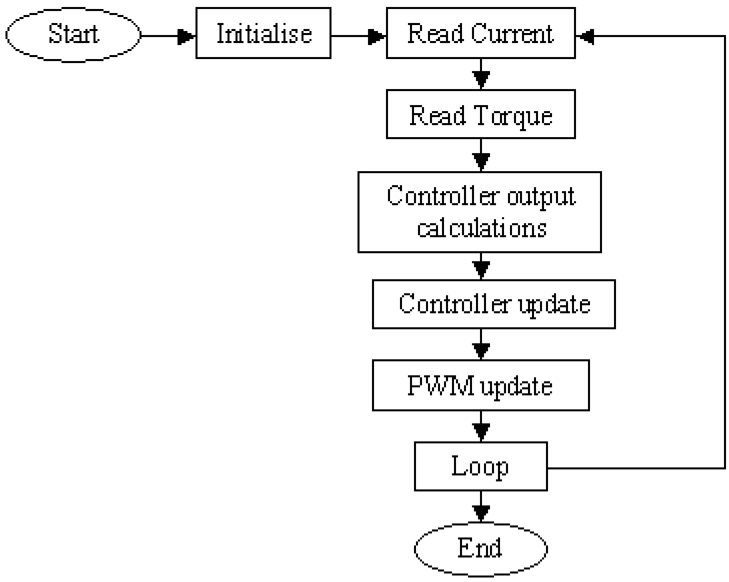


FIGURE 4.1: THE CONTROLLER PROGRAM FLOWCHART.

The initialisation stage defines all of the required variables required to perform the operations of the controller. These include the variables needed for the controller calculations developed from the Simulink model (Figure 3.2), the inputs and outputs for the Atmel and variables used for various other operations throughout the program. The variables are then initialised to their starting values. The settings for the Atmel are also given in this section to define I/O port settings, Timer/Counter and UART initialisation, and interrupt enabling.

After initialisation has taken place, the program enters the main loop. Here, the Atmel takes a reading of the current flowing through the motor and power electronics. This current will be represented as a voltage on the A/D converter with the use of low ohmic resistors and an amplifier, which will be discussed further in Hardware Implementation. The value given by the ADC is converted to the actual current with the equation

currentScaler = (4.8/(1023*15))*(4/0.005) Equation 4.1

Motor_Current = ((double)(adval - ref))*currentScaler

where adval is the ADC reading for the current and ref is the voltage of the reference for the current. The currentScaler in the gain factor associated with converting the A/D voltage into a current and is made up of the A/D maximum voltage, 4.8, 10-bit number range of the A/D, 1023, the amplifier gain, 15, the sensing resistors value, 0.005, and the number of resistors, 4. The reference voltage is the value when there is zero current flowing in the motor and only needs to be read in by the A/D once at the start of operation.

The Atmel then takes a reading of the desired torque using the ADC. The torque value is obtained similarly to the current with the equation

torqueScaler = 4.8*40/1023 Equation 4.2

Torque_Input = ((double)adval)*torqueScaler

The torqueScaler is similar to the currentScaler in that it is the gain factor of converting the A/D voltage into a torque and includes the amount of torque represented by one volt, 40. There is also an option to obtain the desired torque by using the UART. The torque would be recorded on an interrupt by the UART as given in the UART interrupt service routine. Once the value has been recorded, the torque variable will be updated with this value every time the read torque method is called.

Once the current and torque readings have been entered, the program continues to calculate the output using the code produce by the Simulink model of the controller. The program proceeds to work out each of the controller outputs from Figure 3.2 to produce the duty ratio that is needed by the dynamometer to achieve the given torque. This is followed by an update of the controller, which revises the integrator block and makes sure it is within the set limits.

The last task to be completed by the program is to update the PWM value. Since the duty ratio is a value between 0 and 1, it needs to be multiplied by 255, for 8-bit PWM mode,

and then stored into the Output Compare register for an interrupt on the Timer/Counters. Once the Timer/Counters reach this value, the interrupt will cause the output to pulse high or low, depending on the previous operation, thus producing the desired PWM signal. The total process continues to repeat, with each cycle taking about 1.7ms, until it is terminated.

4.2 Hardware

The hardware for this thesis is made up of three sections: the microcontroller, the power electronics and the dynamometer.

4.2.1 Microcontroller

The Atmel for this thesis has been included on the STK200 evaluation board. This board allowed for easy access to all I/O ports, UART and power connections. It contains a number of switches and LEDs that can be used for applications and supports a number of different Atmel devices.

The Atmel has a number of inputs and outputs connected to its ports, including the desired torque input, current measurements from the power electronics and dynamometer, and the PWM signals to control the switching. The desired torque input is supplied by a potentiometer connected to the ADC of the Atmel. The potentiometer is used to vary the voltage to the Atmel, an increase in voltage representing a desire to increase the torque of the dynamometer. This voltage/torque relationship was given in Programming Review. 5 volts is supplied to the potentiometer giving the signal voltage in the range of 0-5V for the Atmel's ADC.

The current feedback and PWM signals are sent to the power electronics through a connector board (see Appendix B). This board is designed to fit into the PALCE22V10H (Programmable Logic chip) socket on SunShark Motor controller given in Appendix A.

Since the MOSFET driver requires high and low sides for the PWM signals, an inverter is required to invert the signals from the Atmel to produce the two sets of PWM. The chip

selected to do this was the 74HCT04N high-speed Hex inverter. The main specification concern with using this chip is the propagation delay produced, which is stated as 8ns [14]. However, this compared to the switching frequency of the PWM (about 15.69kHz) and the fact that the MOSFET driver protects against shoot-through currents means that the delay doesn't have any effect on the switching.

The other major section on the connector board is the current sensing circuitry. Since the sensing resistors need to be small as to not effect the power electronics, the voltage proportional to the current is also small. Therefore, this voltage needed to be amplified for the ADC on the Atmel. This was achieved using an INA122 precision instrumentation amplifier. The INA122, as given in its datasheet [12], is used for accurate, low noise differential signal acquisition and provides excellent performance with very low quiescent current. It has a dual power supply of ±15V (since the SunShark Motor controller also has a ±15V supply) to allow the use of a 2.5 reference voltage. With a reference voltage, the output to the amplifier is added to this value. This allows the Atmel to measure negative currents for the situation when the dynamometer is operated in reverse, where a voltage below 2.5V represents a negative current. The reference voltage was obtained by using a voltage divider of two large resistors of equal value with a 5V supply. This voltage was fed into a LM358N operational amplifier [13] in a voltage follower configuration. By doing this, the 2.5V reference is given to the instrumentation amplifier with low impedance to preserve good common-mode rejection.

The gain on the instrumentation amplifier is adjusted with a single resistor, R_G, and is given by the equation

$$Gain = 5 + \frac{200k\Omega}{R_G} \qquad \text{Equation 4.3}$$

The gain was calculated using the following, derived from the maximum current sensing and the voltage range on the Atmel's ADC.

$$V_{sense\ \max} = I_{\max} \times R_{sense} = 125 \times (0.005/4) = 0.156V \qquad \text{Equation 4.4}$$

$$Gain = \frac{V_{adc}}{V_{sense\ \max}} \approx 15 \ \left(with\ some\ m\arg in\right) \qquad \text{Equation 4.5}$$

Using equation 4.3,

$$R_G = \frac{200k}{Gain - 5} = 20k\Omega \qquad \text{Equation 4.6}$$

With the gain calculated above, the precision of the readings of the ADC worked at as

$$I_{sense} = \left(\left(\frac{4.8}{1023}\right)\Big/15\right)\Big/(0.005/4) = 0.264A \qquad \text{Equation 4.7}$$

This means that the Atmel's ADC will detect every 0.264A of current flowing through the motor and the sensing resistors, or every 0.2% of the total current.

4.1.2 Power Electronics

The switching scheme implemented for the power electronics was based on PWM with unipolar voltage switching as described in Chapter 2, where each of the legs of the full bridge converter are switched independently of each other. This system of switching was modified to be multi-phase or phase shifted switching. Phase shifted switching controls a number of switch sets each out of phase from each other by an equal value. For this thesis, there are two phases to be controlled 180 degrees out of phase. This is demonstrated in Figure 4.2.

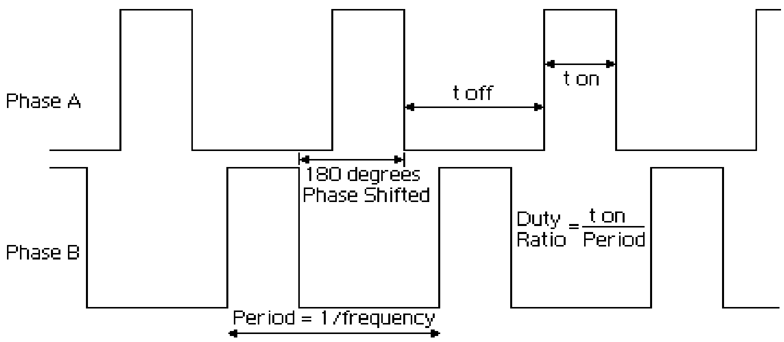


FIGURE 4.2: PWM PHASE SHIFTED SWITCHING.

The top PWM signal controls phase A of the motor controller and phase B is controlled by the bottom PWM. This results in an output that has twice the frequency as bipolar switching and improves the ripple current, which gives a more stable input to the motor.

The power losses from the switches are due to conduction and switching as stated in Chapter 3. The maximum conduction losses for the six MOSFETs connected in parallel are calculated as follows:

$$P_{cond} = 125^2 \times 0.055 \times \frac{0.0000637}{0.0000637} = 144W\ total\ or\ 24W\ per\ MOSFET$$

The maximum switching losses are calculated as:

$$P_{sw} = \frac{1}{2} \times 140 \times \frac{125}{6} \times 15690 \times \left(23 \times 10^{-9} + 90 \times 10^{-9}\right) = 2.6W\ per\ MOSFET$$

These give the total power losses per MOSFET as 26.6W. The IR2130 bridge driver prevents the other losses mentioned in Chapter 3 caused by shoot through currents. It makes sure that there is some 'dead time' between the high and low side turning on as a protection function, even if the inputs tell it otherwise.

The power losses will cause heat to be created in the MOSFETs, requiring an appropriate heat sink to be attached. The size and type of this heat is worked out using the equations given in Chapter 3, in particular, Equation 3.7. By setting the ambient temperature to 25˚C and the junction temperature of the MOSFET to 100˚C and obtaining the thermal resistances related to the MOSFETs gives the thermal resistance of the heat sink required.

$$R_{\theta sa} = \left(\frac{T_j - T_a}{P_d}\right) - \left(R_{\theta jc} + R_{\theta cs}\right) = \left(\frac{100 - 25}{26.6}\right) - \left(0.45 + 0.24\right) = 2.13°C/W$$

This is the thermal resistance for a junction temperature of 100˚C. If a lower value heat sink is used, it will decrease this temperature, which is desirable. Heat sinks to cover all of the MOSFETs on the motor controller need to have an area of at least 234cm^2, which have a thermal resistance of around 0.5˚C/W [Farnell Catalogue]. This size heat sink will ensure that the MOSFETs won't ever over heat for the powers utilised for the given specifications.

The design of the auto transformer was achieved using Equation 3.8. Using the input voltage, V_1 = 120V, and the frequency of the PWM switching, f = 15.69kHz, gave

$$N_1 = \frac{120}{4 \times 15690 \times A_{core} \times B_{\max}}$$

The area of the core and the flux density are parameters of the transformer. Since the current through the motor is 9A, a reasonably large transformer with low power loss was

selected, the ETD59 [15]. It has an effective core area of 368mm^2 and a flux density of 0.2Telsa at 25kHz, which gives the number of primary turns as

$$N_1 = \frac{120}{4 \times 15690 \times 368/1000^2 \times 0.2} = 26 \ \ turns$$

Since an auto transformer is used, this is the total number of turns required, giving 13 turns each for the primary and secondary windings.

4.1.3 Dynamometer

The dynamometer that this thesis was designed for was unavailable to be tested with. Therefore, another DC motor was required for testing the motor torque controller designed in this thesis. The DC motor used for testing has the specifications given in Table 4.1.

Motor Specifications	
Power	1.1kW
Speed	1500rpm
Armature – voltage	180V
- current	8A
Field - voltage	200V
- current	0.24A
Revised Scope	
Voltage	120V
Current	8A

TABLE 4.1: SPECIFICATIONS OF THE DC MOTOR AND THE REVISED SCOPE.

The use of the above motor meant that some of the original design required adjusting. The main difference is the amount of current and the torque it can deliver, which is much less than originally designed. This affected much of the design and needed to be readjusted for the motor. Table 4.2 shows all of the changes that were required to control this motor successfully.

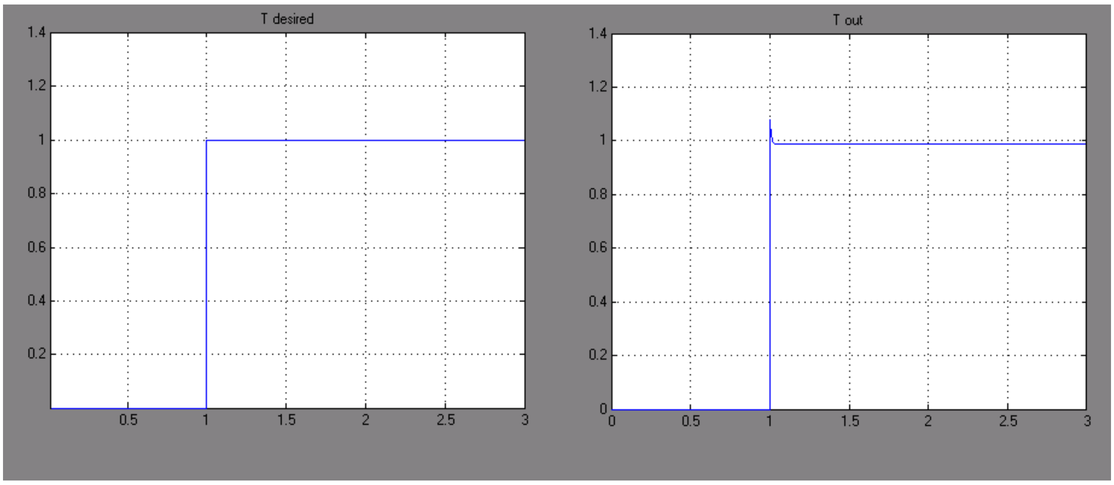
Hardware - Current sensing resistors	One 0.005Ω 5W resistor
- $V_{sense\ max}$	0.04V
- I_{sense}	0.0167A (0.2%)
- Gain of INA122 Amplifier	56.28
- INA122 Amplifier gain resistor, R_G	3.9kΩ
- Conduction losses, P_{cond}	0.098W
- Switching losses, P_{sw}	0.142W
- Heat Sinking	None
- Field Control	None
Software - Varm to Duty ratio gain block	1/120
- Current Limiter	8
- Voltage Limiter	120
- Current equation	currentScaler = (4.8/(1023*56.28))/0.005;
- Torque equation	torqueScaler = 4.8*2/1023;

TABLE 4.2: CHANGES TO THE DESIGN FOR THE MOTOR.

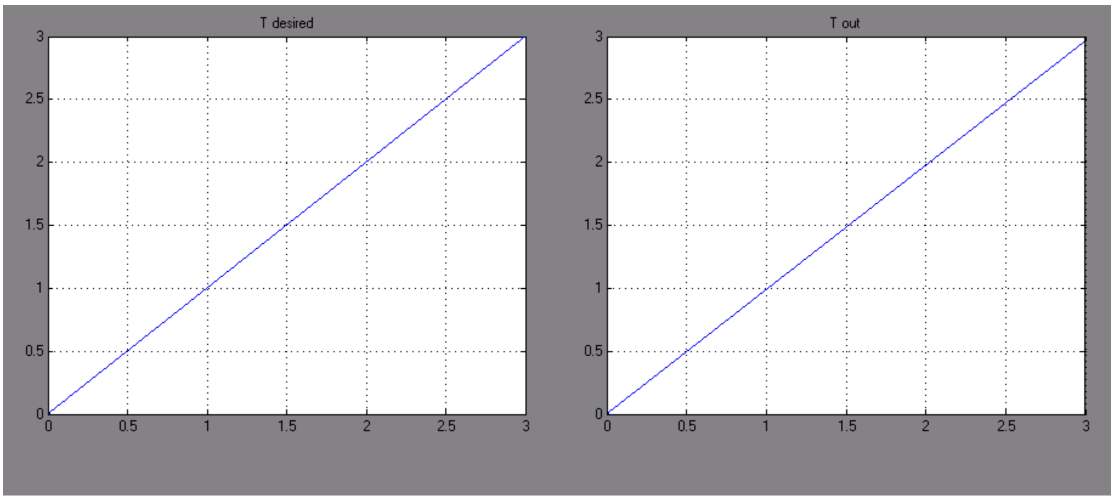
Chapter 5 Experimental Results and Analysis

5.1 Simulation Results

The results from the simulation of the designed controller and the motor model in Simulink are shown in Figure 5.1 below. The first graph shows the output response from a step input and the second shows the response to a ramp input.



(A)



(B)

FIGURE 5.1: SIMULATED OUTPUT TORQUE RESPONSE FROM (A) A STEP INPUT AND (B) A RAMP INPUT.

The step input response shows that the system reacts very quickly, almost instantly rising up to the desired level. There is a small and acceptable overshoot of around 8 per cent and a steady-state error of 1.22 per cent. The output is also very stable and doesn't produce any oscillations. The ramp input response also shows that the output follows closely to the input. It is only slightly behind the input at 3 seconds and shows a good smooth rise. These responses, however, are very unlikely to occur when implemented due to hardware limitations. The practical results would be much slower due to the time taken for the Atmel to cycle through the controller program as well as the fact that the electrical and mechanical time constants of the motor greatly reduce the time it can respond to an input. The simulation results do show that the control system has been optimised as much as possible.

5.2 Controller Testing

There were a number of tests carried out with the Atmel, controller program and the SunShark motor controller to analysis the operation of the design. The first tests involved the Atmel and the controller program to see if it would match the simulation results. Values for the desired torque and current feedback were hard coded into the Atmel and the PWM response was checked against the same simulation conditions. These proved to be successful with the PWM matching exactly (apart from the actual time taken) with the results gained from Simulink, even showing the small overshoot before reaching steady state. This showed that the controller program was working as anticipated.

The next test involved checking the PWM signals by varying the input voltage on the A/D converter. This was done using a potentiometer, and demonstrated that the PWM changed proportionally with the voltage and displayed very good phase shifted PWM on the output of the Atmel.

The third set of tests included two potentiometers used with the controller program to simulate the conditions when connected to a motor. The first potentiometer represented the desired torque input and the second was used to produce a current feedback voltage. As the torque voltage increased, the PWM duty ratio increased with it until the current voltage was manually increased. This then caused the PWM duty ratio to decrease to

compensate for the increase in current. When the current voltage was the right value for the desired torque input, the PWM would hold constant meaning that the existing duty ratio was at the correct level. These tests showed that the current feedback was working well with the desired torque input, again showing that the controller program was as expected.

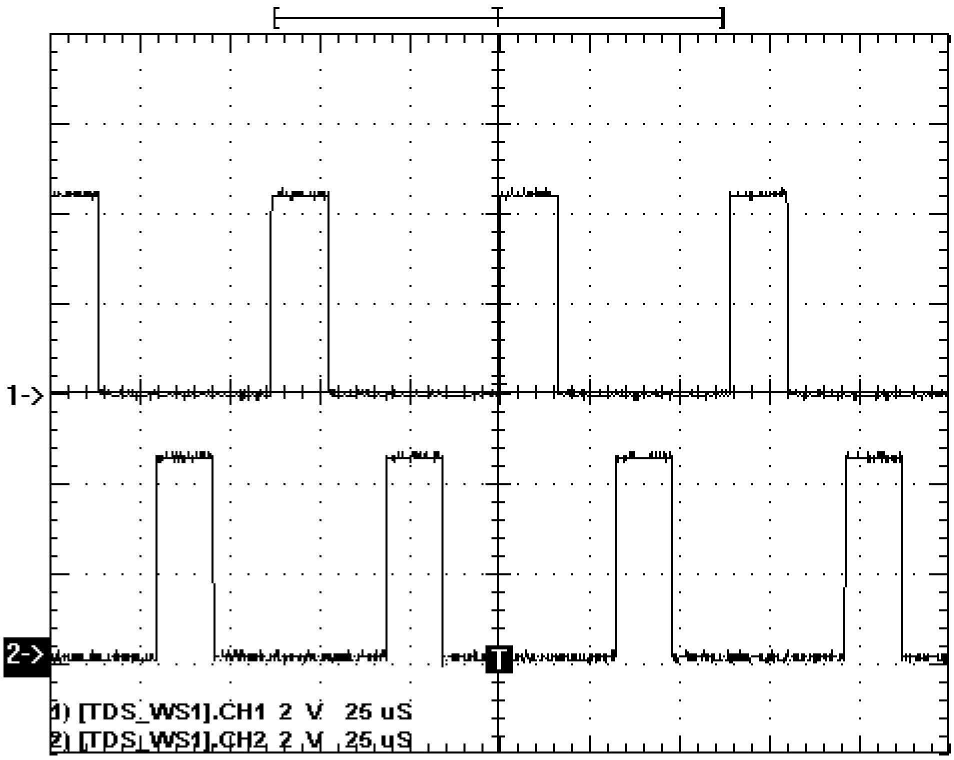


FIGURE 5.2: PWM OUTPUT FROM ATMEL TESTING.

The final testing with the controller involved connecting the Atmel to the SunShark motor controller with the connector board. Initially, only one phase of the motor controller was tested with the PWM controlled with a potentiometer connected to the A/D. The output voltage was as expected, being proportional to the duty ratio. From here, the second phase was also controlled with the auto transformer connected between the two output phases. This once more was successful giving the correct output voltage from the transformer.

5.2 Motor Testing

The practical results gained from the motor where good in some respects, but others not so successful. The motor was controlled with a voltage source of 30V and limited to 3A. The output of the motor controller, PWM, was first controller using an open loop configuration. This was achieved by using a potentiometer to set the PWM duty ratio through the Atmel's A/D converter, which outputted the two-phase signals. The motor was controller on a test bench and was coupled to another DC motor to provide a load. The results from this are shown in Figure 5.3.

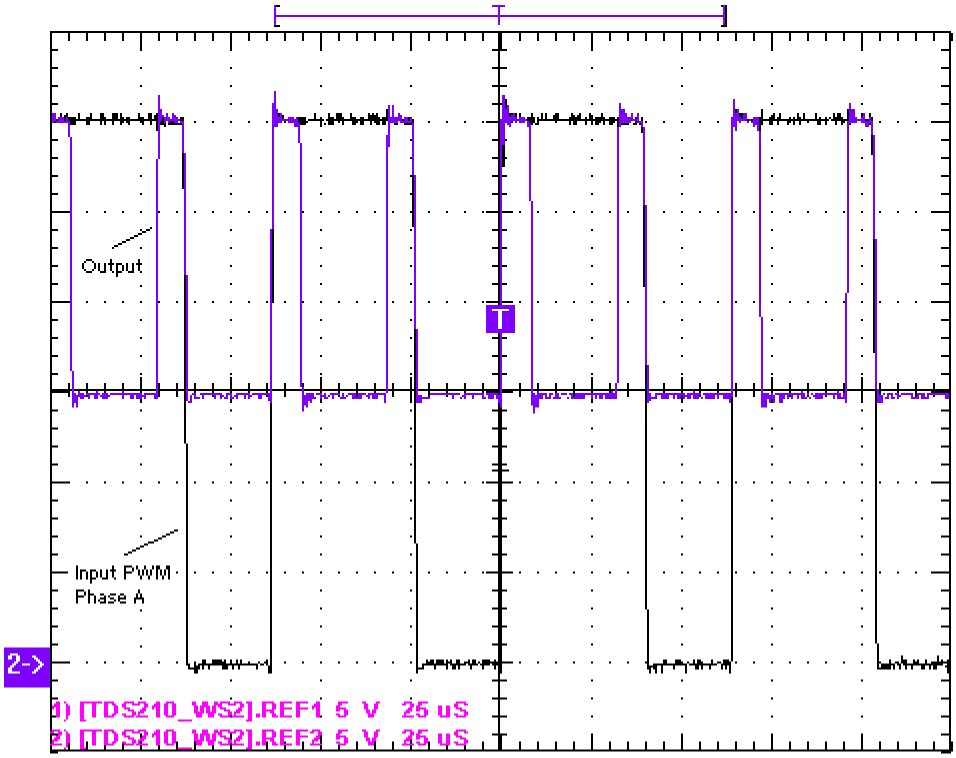


FIGURE 5.3: OPEN LOOP RESPONSE OF THE OUTPUT AND ONE OF THE INPUT PWMS.

The output was produced through the auto transformer from the two PWM signals, which produced exactly as expected. As the duty ratio was increased from zero, the output from the transformer would pulse to half the supply voltage at twice the switching frequency of each motor controller phase. This continued to 50% duty ratio where the output was a flat, constant voltage at half the supply. From here, the output would continue to pulse at double the phase frequency from half voltage to full voltage until it arrived at 100% duty

ratio. Figure 5.3 shows the output from a duty ratio of greater than 50%, with the pulses rising up from half the supply voltage at twice the single phase frequency.

These results proved that the A/D and PWM were working and that the switching scheme, power electronics and auto transformer worked as predicted. The motor performed equally well used to drive a load or when suppling a load to another motor.

However, problems occurred when attempting to close to loop with a current feedback to the designed controller program in the Atmel. When the desired torque was entered into the system, the PWM signals would max out and not reduce again when the torque was decreased. This was due to the current measurements made with the current sensing resistor. The voltage drop across it didn't represent the actual current flowing through the armature of the motor. The values recorded voltages were much lower than anticipated, with a current of around 2.5A only giving a voltage of about 6mV across 0.005Ω. Therefore, the current must have either found a different path to flow instead of through the sensing resistors or more likely the resistance was too small to provide any voltage drop. The result of this was that the controller program wasn't sensing any current and so proceeded in increasing the duty ratio to its maximum to produce more current. This was the only major weak point in the design and contributed to the limited practical success of this thesis.

Chapter 6 Summary, Conclusions and Future Work

6.1 Synopsis and Conclusions

The design and implementation of a torque controller system for a DC motor has been carried out using a microcontroller and power electronics. The original design was based on the ASEA DC Dynamometer using power specifications of 140V and 125A, which were changed for a more accessible and desirable DC motor with reduced specifications of 120V and 8A.

A number of aspects have been covered in the design process including modelling, controller design with a microcontroller, power electronics and DC machines. All of which are implemented to provide a road load torque controller to test new motors and drivers.

The modelling provided a foundation for the design of the controller and gave a look at what was expected when applied with hardware. The simulations gave very good results, although they were never expected to occur in practical implementation due to response times of the power electronics and the motor. The modelling helped immensely in optimising the system.

The modelled design was applied reasonably easily to the Atmel microcontroller due to Simulink and the use of C code. The Atmel provided a number of features, in particular, the A/D converter, PWM mode timers and the UART. The Atmel gave near perfect switching signals for the power electronics and allowed for easy and quick modifications to the controller design. There are also options available for extending the design given involving field control of DC motors, serial torque input with the UART and data logging capabilities.

The power electronics came in the form of a DC-DC converter previously created for motor control of the SunShark Solar Car. The motor controller required little modification, which involved developing a connector board from the Atmel, adjusting the current

sensing resistors and designing an auto transformer for the output to the motor. These were achieved successfully apart from the sensing resistor.

The results from testing the design on a motor showed that the vital link in a closed loop system is the sensing technique applied to provide the feedback. The sensing resistors, together with the instrumentation amplifier, proved to be insufficient in supplying the current produced in the motor and power electronics. At the time of writing this thesis, this problem was not overcome, however, with some more closer analysis, it should be solved. Another solution could be to use a current transducer of some sort to provide more accurate and reliable measurements, although this would be a costly alternative to sensing resistor.

Although the final practical testings fell short of expectations at the time of writing, this thesis has been successful in providing a solid design for torque control of DC motors that has demonstrated almost complete functionality. The design method used is easy to follow to allow future advancements to be made without too much difficulty.

6.2 Future Work

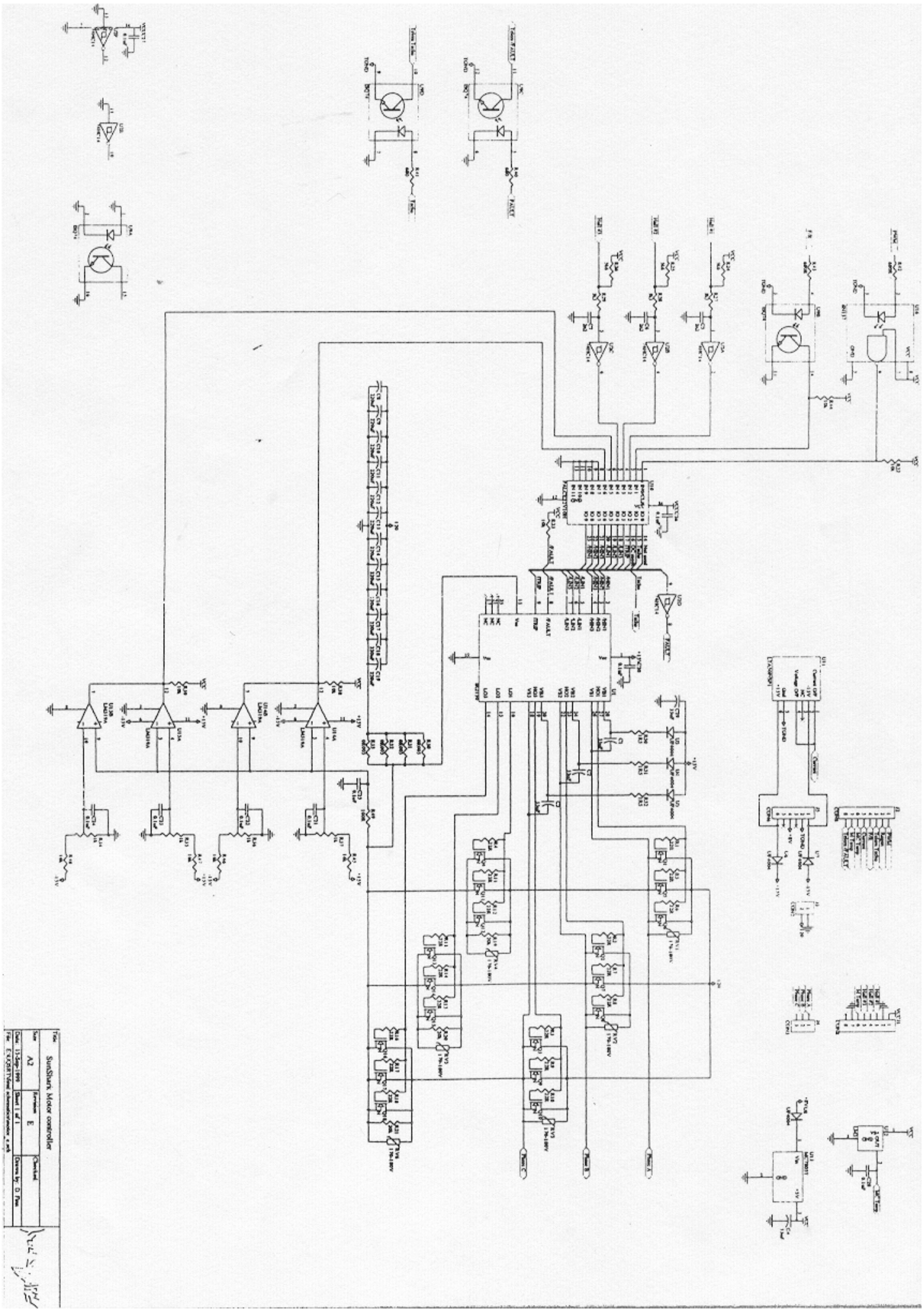
There are a number of topics for future work and development related with the motor torque controller designed in this thesis. These may include:

- Obtaining greater power specifications for the power electronics to be used with a larger dynamometer. The increased current would allow for greater torques to be used while the increase in voltage would raise the speed, producing a much better road load simulator for testing electric motors and drivers.
- Using the UART option to input the desired torque. This would let more accurate torque values to be used and obtain a slight reduction in the time for the controller code to cycle.
- Developing test bench software for computer control and monitoring via a PC. This would be combined with the UART option and provide a means for data logging. This could gather results on the current, voltage, torque and speed of the dynamometer and test motor as well collecting data on the overall efficiency and performance.

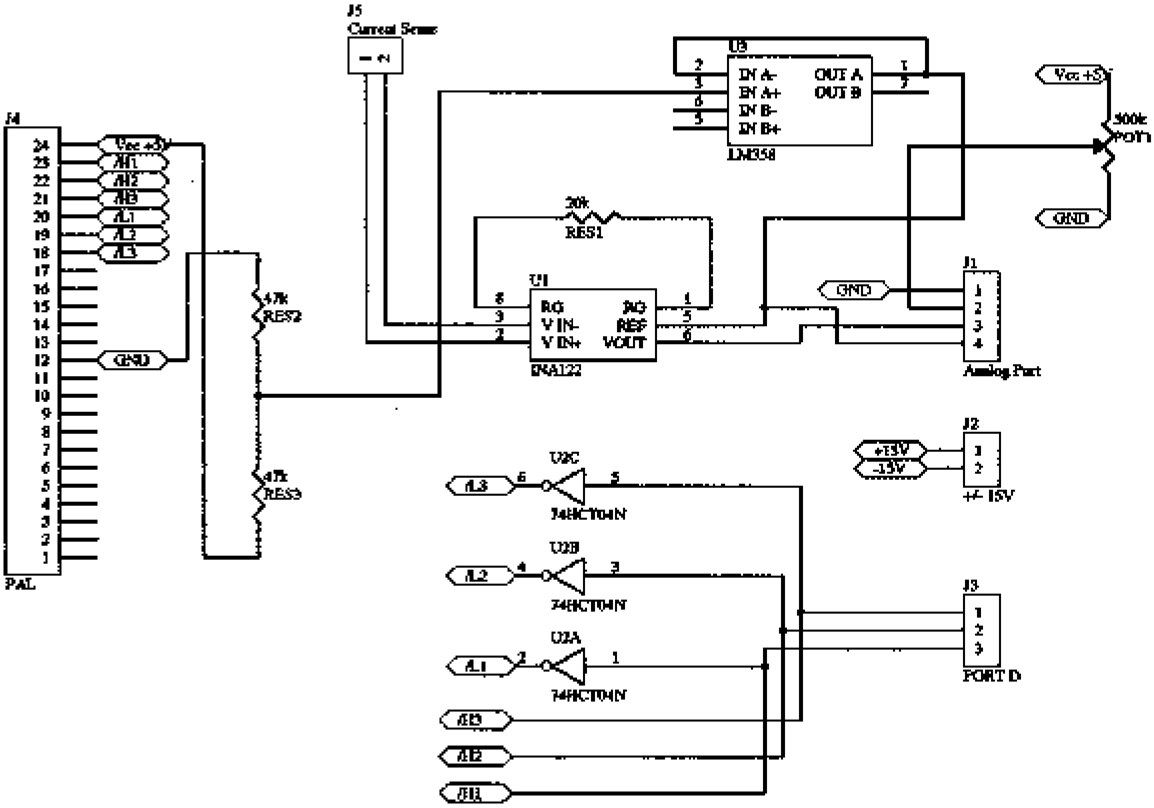
- Design of the regenerative power bus to recirculate the power obtained from the dynamometer back into the testing motor. This system would need a power dissipating resistive load and switch to disperse the power when both motors are braking, which would be controlled by the motor controller.
- Combining the designed dynamometer controller in this thesis with the motor controller of the testing motor, the data logging and the regenerative bus into a complete motor test bench system, as shown in Figure 1.1. All of the modules would be digitally controlled via a PC allowing for quick and easy operation.

Appendices

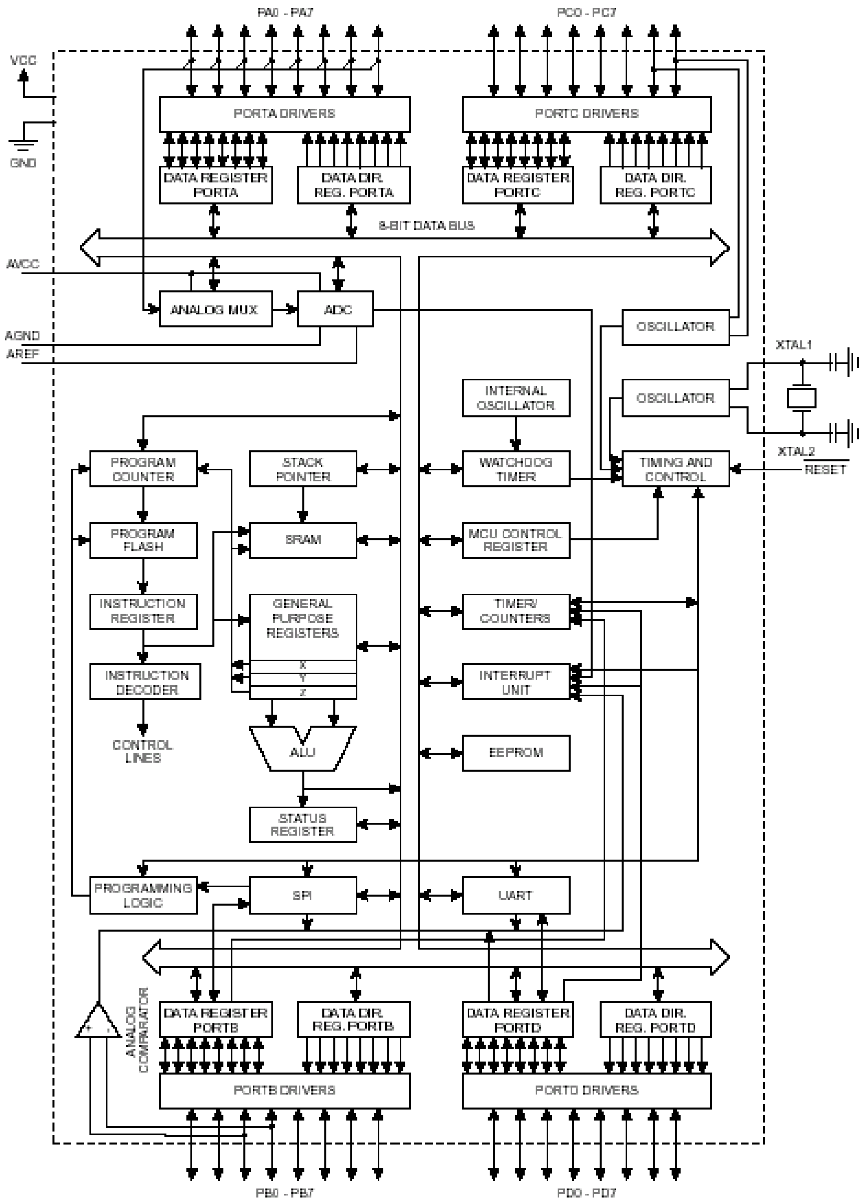
Appendix A – SunShark Motor Controller



Appendix B – Connector Board



Appendix C – Atmel AT90S8535 Block Diagram



Appendix D – Program Listing

```
/********************************************
This program was produced by the
CodeWizardAVR V1.0.1.7b Evaluation
Automatic Program Generator
© Copyright 1998-2001
Pavel Haiduc, HP InfoTech S.R.L.
http://infotech.ir.ro
e-mail:dhptechn@ir.ro , hpinfotech@mail.com

Project :     Thesis - torque motor control
Version :
Date    :     20/07/2001
Author  :     Jeffrey Jordan
Company :              University of Queensland
Comments:


Chip type              : AT90S8535
Clock frequency        : 4.000000 MHz
Memory model           : Small
Internal SRAM size     : 512
External SRAM size     : 0
Data Stack size        : 128
********************************************/

#include <90s8535.h>
#include <delay.h>
// Floating number to string
#include <Ftoa.h>
// String to floating point number
#include <Atof.h>
// Standard Input/Output functions
#include <stdio.h>
// standard library
#include <stdlib.h>
// charater type library
#include <ctype.h>

#define  UART_txReady       0x40

// All variables for the controller, block parameters from simulink model
double Gain_Gain;                                  // Expression: 1.152
double Current_Limiter_US;                         // Exp: 14
double Current_Limiter_LS;                         // exp: -14
double Gain1_Gain;                                 // exp  2.84
double Discrete_Time_Integ_IC;                     // exp  0
double Discrete_Time_Integ_US;                     // exp  120
double Discrete_Time_Integ_LS;                     // exp  0
double Voltage_Limiter_US;                         // exp  120
double Voltage_Limiter_LS;                         // exp  0
double Varm_to_Duty_ratio_Gain;                    // exp  1/120
double Gain2_Gain;                                 // exp  310

// Inputs, output
double Torque_Input;
double Motor_Current;
double Duty_Ratio;
double Field_Duty_Ratio;

// Limited discrete integrator block
double Discrete_Time_Integrator;
// for discrete integrator gain and update
double Gain2;
// pwm for updating the output duty ratio
double pwm;
// the desired torque from the user through comms
char Tdesired[15];
// a/d value
int adval;
// desired torque from the comms, as a double
```

```
double Tinput;
// int to test if first current read, ie zero current for the ref, 0 no, 1 yes
int first;
// reference a/d reading for +ve and -ve current reading
int ref;

// UART Receiver interrupt service routine
#pragma savereg-
interrupt [UART_RXC] void uart_rx_isr(void)
{
	unsigned char received;
	int i;
	received = getchar();
	delay_ms(10);
	if (isdigit(received)) {
		i = 0;
		// providing only digits and 1 decimal point received, 15 is array length
		while ((received != 's')&(i < 14)) {
			Tdesired[i] = received;
			received = getchar();
			++i;
		}
		// convert to a double
		Tinput = atof(Tdesired);
		printf("%s \n",Tdesired);
		putchar(13); // line feed
		// clear Tdesired
		for (i=0; i<=14;i++) {
			Tdesired[i] = '\0';
		}
	}
}
#pragma savereg+

// Timer 1 output compare A interrupt service routine
interrupt [TIM1_COMPA] void timer1_compa_isr(void)
{
	// PWM - do nothing
}

// Timer 1 output compare B interrupt service routine
interrupt [TIM1_COMPB] void timer1_compb_isr(void)
{
	// PWM - do nothing

}

// Read the ADC conversion result
unsigned int read_adc(unsigned char channel)
{
	unsigned int channelValue;
	ADMUX = channel;
	// Start Conversion
	ADCSR.6 = 1;
    // Wait until A2D finished
	while (ADCSR.4 == 0);
	// clear the ADC complete flag
	ADCSR.4 = 1;
	// Read ADC-result - always read ADCL first
	channelValue = ADCL;
	channelValue = channelValue + ((int)(ADCH) << 8);

	return channelValue;
}

/*
 * initialise_param - initialise all the block parameters and other variables
 */
void initialise_param(void)
{
   Gain_Gain = 1.152;
   Current_Limiter_US = 14.0;
   Current_Limiter_LS = -14.0;
   Gain1_Gain = 2.84;
   Discrete_Time_Integ_IC = 0.0;
   Discrete_Time_Integ_US = 120.0;
```

```
   Discrete_Time_Integ_LS = 0.0;
   Voltage_Limiter_US = 120.0;
   Voltage_Limiter_LS = 0.0;
   Varm_to_Duty_ratio_Gain = 0.008333333333333;
   Gain2_Gain = 310.0;

   Torque_Input = 0.0;
   Motor_Current = 0.0;
   Duty_Ratio = 0.0;
   Field_Duty_Ratio = 0.0;
   Tinput = 0.0;

   Discrete_Time_Integrator = Discrete_Time_Integ_IC;

   first = 0;
}

/*
 * read_current - take a reading of the motor current
 */
void read_current(void)
{
		// a/d voltage       - 4.8
		// 10 bit            - 1023
		// amp gain          - 56.28
		// sensing resistors - 0.005
		// no. of resistors  - 1
		double currentScaler;
		//currentScaler = (4.8/(1023*56.28))*(1/0.005);
		currentScaler = 0.016674065;
		// read in the reference voltage for the current, pin 5
		if (first == 0) {
			ref = read_adc(6);
			first = 1;
		}
		//read in the current through the a/d converter, pin 6
		adval = read_adc(6);

		// convert the a/d reading into a current in Amps
		Motor_Current = ((double)(adval - ref))*currentScaler;
}

/*
 * read_torque - get the desired torque
 */
void read_torque(void)
{
		double torqueScaler;
		torqueScaler = 0.009384164223; // = 4.8*2/1023, 1 volt = 2 Nm of torque
		// read in the desired torque
		// two methods
		// a/d converter - pin 7
		// voltage between 0 and 4.8V unless external reference voltage used
		adval = read_adc(7);  // actual value in volts = (adval/1023) * 4.8V

		Torque_Input = ((double)adval)*torqueScaler;

		// serial comms - need to use uart interrupt
		//Torque_Input = Tinput;
}

/*
 * controller_outputs - calculates all of the block outputs for the controller
 */
void controller_outputs(void)
{
		// Local Temp variables for controller calculations
		double temp1;
		double temp2;
		double temp3;

		// start controller calculations

		// Gain block Gain
		temp2 = Torque_Input * Gain_Gain;
```

```
		// Saturation block - current limiter
		if (temp2 >= Current_Limiter_US) {
				temp2 = Current_Limiter_US;
		} else if (temp2 <= Current_Limiter_LS) {
				temp2 = Current_Limiter_LS;
		}

		// Sum block 1
		temp2 = temp2 - Motor_Current;

		// Gain block Gain1
		temp3 = temp2 * Gain1_Gain;

		// Limited discrete integrator block
		temp1 = Discrete_Time_Integrator;
		if (temp1 >= Discrete_Time_Integ_US) {
				temp1 = Discrete_Time_Integ_US;
		} else if (temp1 <= Discrete_Time_Integ_LS) {
				temp1 = Discrete_Time_Integ_LS;
		}

		// Sum Block 2
		temp3 = temp3 + temp1;

		// Saturate Block Voltage Limiter
		if (temp3 >= Voltage_Limiter_US) {
				temp3 = Voltage_Limiter_US;
		} else if (temp3 <= Voltage_Limiter_LS) {
				temp3 = Voltage_Limiter_LS;
		}

		// Gain Block Varm to Duty ratio
		temp3 *= Varm_to_Duty_ratio_Gain;

		// Output Duty Ratio
		Duty_Ratio = temp3;

		// Gain Block Gain2
		Gain2 = temp2 * Gain2_Gain;
}

/*
 * controller_update - update the controller integrator block
 */
void controller_update(void)
{
		// Perform update
		// Limited DiscreteIntegrator Block Discrete-Time Integrator
		//  time step of 0.0017 seconds
		Discrete_Time_Integrator = Discrete_Time_Integrator + 0.0017 * Gain2;
		// limit states
		if (Discrete_Time_Integrator > Discrete_Time_Integ_US) {
				Discrete_Time_Integrator = Discrete_Time_Integ_US;
		} else if (Discrete_Time_Integrator < Discrete_Time_Integ_LS) {
				Discrete_Time_Integrator = Discrete_Time_Integ_LS;
		}
}

/*
 * pwm_update - set the pwm output to the correct duty ratio for the next interrupt
 */
void pwm_update(void)
{
		// phase b, non-inverted
		pwm = 255 * Duty_Ratio;
		OCR1A = pwm;

		// phase a, inverted
		pwm = 255 * (1 - Duty_Ratio);
		OCR1B = pwm;
}

/*
 * field_update - set the field pwm output to the correct duty ratio for the next interrupt
 */
void field_update(void)
```

```
{
		pwm = 255 * Field_Duty_Ratio;
		OCR2 = pwm;
}

void main(void)
{
// Declare your local variables here
char string[15];
unsigned char pD;
double dr;

// Input/Output Ports initialization
// Port A
PORTA=0x00;
DDRA=0x00;

// Port B
DDRB=0xFF;
PORTB=0xFF;

// Port C
//PORTC=0x00;
//DDRC=0x00;

DDRC=0xFF;
PORTC=0xFF;

// Port D
PORTD=0x00;
DDRD=0xB0;

// Timer/Counter 0 initialization
// Clock source: System Clock
// Clock value: Timer 0 Stopped
// Mode: Output Compare
// OC0 output: Disconnected
TCCR0=0x00;
TCNT0=0x00;

// Timer/Counter 1 initialization
// Clock source: System Clock
// Clock value: Timer 1 Stopped
// Mode: 8 bit Pulse Width Modulation
// OC1A output: Non-Inverted
// OC1B output: Inverted
// Noise Canceler: Off
// Input Capture on Falling Edge
TCCR1A=0xB1;
TCCR1B=0x00;
TCNT1H=0x00;
TCNT1L=0x00;
OCR1AH=0x00;
OCR1AL=0x00;
OCR1BH=0x00;
OCR1BL=0x00;

// Timer/Counter 2 initialization
// Clock source: System Clock
// Clock value: Timer 2 Stopped
// Mode: Pulse Width Modulation
// OC2 output: Inverted
TCCR2=0x60;
ASSR=0x00;
TCNT2=0x00;
OCR2=0x00;

// Timer(s)/Counter(s) Interrupt(s) initialization
TIMSK=0x18;

// External Interrupt(s) initialization
// INT0: Off
// INT1: Off
GIMSK=0x00;
MCUCR=0x00;
```

```
// UART initialization
// Communication Parameters: 8 Data, 1 Stop, No Parity
// UART Receiver: On
// UART Transmitter: On
UCR=0x98;
// UART Baud rate: 9600
UBRR=0x19;

// Analog Comparator initialization
// Analog Comparator: Off
// Analog Comparator Input Capture by Timer/Counter 1: Off
ACSR=0x80;

// ADC initialization
// ADC Clock frequency: 2000.000 kHz
ADCSR=0x91;

// Global enable interrupts
#asm("sei")

// clear rs232 buffer
UDR=0;

// initialise parameters
initialise_param();

// start timer1 counter to run on the clock
TCCR1B = 0x01;
// start timer2 counter to run on the clock
TCCR2 = 0x61;
// initialise the duty ratio to zero
// phase b, on timer1, which has its output non-inverted
OCR1A = 0;
// phase a on timer1, inverted
OCR1B = 255;
// initialise the field duty ratio to zero
OCR2 = 0;

while (1)
    {
        // Start of controller code

        // read port d, if not pin 3 (switch 3 not pressed) do nothing, else start
        pD = PIND;
        PORTB = pD;

        if (pD != 71)                    // do nothing
        {
            // reset everything when pin 6 switch pressed
            if (pD == 15) {
                initialise_param();
                OCR1A = 0;
                OCR1B = 255;
                OCR2 = 0;
            }
            // a/d reading when pin 2 switch pressed
            if (pD == 75) {
                // while switch 6 not pressed
                // read the a/d channel 7 and use this value as the duty ratio
                PORTB = pD;
                delay_ms(100);
                pD = PIND;
                while (pD != 15) {
                    adval = read_adc(7);
                    dr = adval;
                    Duty_Ratio = dr/1023;
                    pwm_update();

                    Field_Duty_Ratio = Duty_Ratio;
                    field_update();

                    pD = PIND;
                    delay_ms(5);
                }

                delay_ms(100);
```

```
                }

        } else                          // start controller
        {
                PORTB = pD;
                delay_ms(500);
                // while switch on pin 6 not pressed
                while (pD != 15) {

                        // get a current reading
                        read_current();
                        // get the desired torque
                        read_torque();
                        // calculate the controller block outputs
                        controller_outputs();
                        // perform update of controller
                        controller_update();
                        // update the PWM to the correct duty ratio
                        pwm_update();

                pD = PIND;

        } // end while pin 6 switch not pressed

                delay_ms(200);

        } // end if not pin 3 switch

    };  // end while 1
} // end main
```

Appendix E – References

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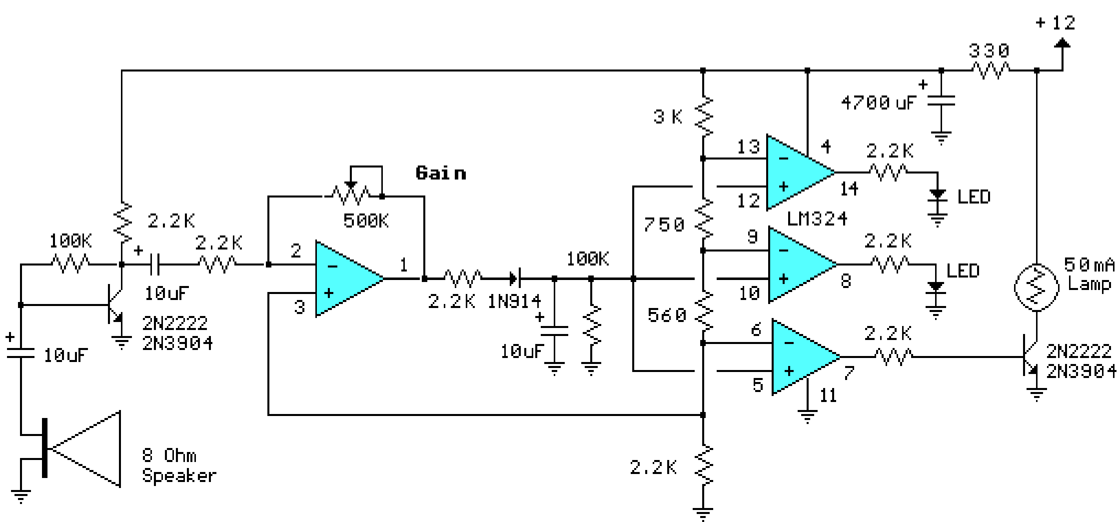
Decibel Meter

The circuit below responds to sound pressure levels from about 60 to 70 dB. The sound is picked up by an 8 ohm speaker, amplified by a transistor stage and one LM324 op-amp section. You can also use a dynamic microphone but I found the speaker was more sensitive. The remaining 3 sections of the LM324 quad op-amp are used as voltage comparators and drive 3 indicator LEDs or incandescents which are spaced about 3dB apart. An additional transistor is needed for incandescent lights as shown with the lower lamp. I used 12 volt, 50mA lamps. Each light represents about a 3dB change in sound level so that when all 3 lights are on, the sound level is about 4 times greater than the level needed to light one lamp. The sensitivity can be adjusted with the 500K pot so that one lamp comes on with a reference sound level. The other two lamps will then indicate about a 2X and 4X increase in volume.

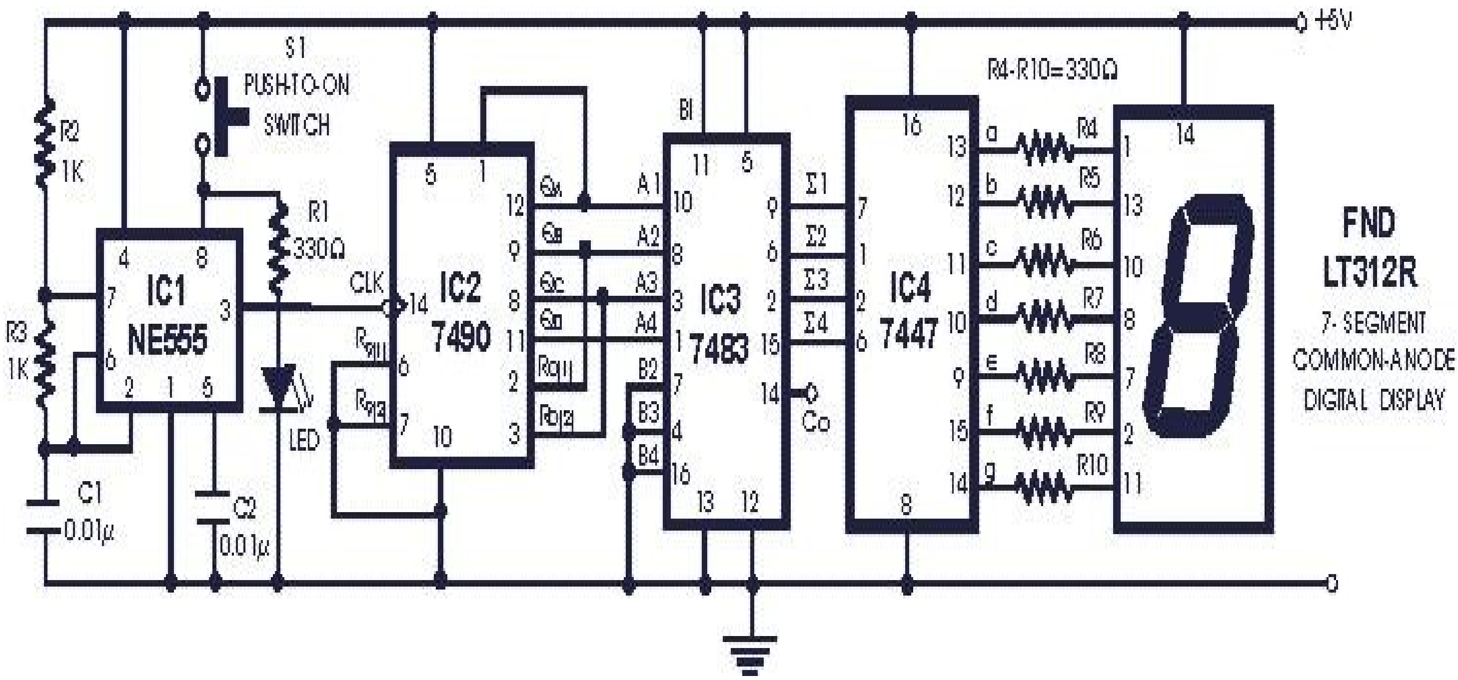
In operation, with no input, the DC voltage at pins 1,2 and 3 of the op-amp will be about 4 volts, and the voltage on the (+) inputs to the 3 comparators (pins 5,10,12) will be about a half volt less due to the 1N914 diode drop. The voltage on the (-) comparator inputs will be around 5.1 and 6.5 which is set by the 560 and 750 ohm resistors.

When an audio signal is present, the 10uF capacitor connected to the diode will charge toward the peak audio level at the op-amp output at pin 1. As the volume increases, the DC voltage on the capacitor and also (+) comparator inputs will increase and the lamp will turn on when the (+) input goes above the (-) input. As the volume decreases, the capacitor discharges through the parallel 100K resistor and the lamps go out. You can change the response time with a larger or smaller capacitor.

This circuit requires a well filtered power source, it will respond to very small changes in supply voltage, so you probably will need a large filter capacitor connected directly to the 330 ohm resistor. I managed to get it to work with an unregulated wall transformer power source, but I had to use 4700uF. It worked well on a regulated supply with only 1000uF.



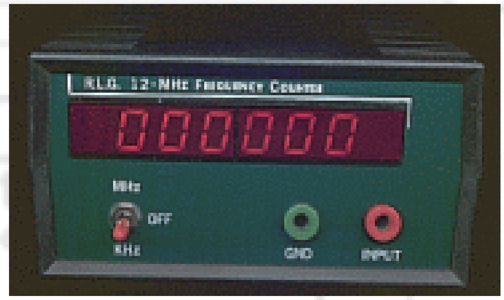
Digital Dice with Numeric Display



The circuit described here is that of a digital dice with numeric display. Timer IC 555 wired as an astable multivibrator produces pulses at about 48 kHz rate. These pulses are fed to pin 14 of the decade counter IC 7490. The oscillator is activated by depression of switch S1. Using different connections for pins 2, 3 (reset to zero inputs Ro(1) and Ro(2)) and the binary output pins 12, 9, 8 and 11 of IC7490, various count ranges can be set. For the given circuit the count range is set as 0 to 5 by connecting QB and QC outputs to Ro(1) and Ro(2) inputs, respectively. At the count of 6, QB and QC outputs of IC2 go high and counter is reset. The binary output pins of the counter IC2 are co-nnected to corresponding input pins of 4-bit binary adder IC3 (7483) which is wired to give binary output equal to binary input+1. Thus the output of the dice ranges from 1 to 6. For obtaining other dice ranges, reset pins 2 and 3 connections may be made as per Table I. The binary summation outputs from IC 7483 are connected to IC4 (7447) which is a BCD to 7-segment decoder/driver. The output from IC4 is connected to a 7-segment common-anode LED display (FNDLT312R). When switch S1 is depressed, the LED (D1) glows and the number displayed at the 7-segment display changes at a rate of about 48,000 times per second. As soon as the switch is released, the last (latest) number remains on display. Thus the circuit performs the function of a random number generator with the displayed number lying within the selected (wired) range.

Handy Dandy Little Circuits

6 Digit Frequency Counter



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Note

This " 6 Digit Frequency Counter " circuit and PCB was designed by Laurier Gendron. It is being made available to hobbyists for personal development only. It cannot be used for commercial purposes of any kind without previous written permission. (10 Feb.2001)

Introduction

Based on the application of the three digit decoder driver chip MC14553 published in the Motorola data manual I undertook the task of designing a 6-digit frequency meter and the results were excellent , simple enough and at a cost of well under $ 50.00 Canadian.

Since the Frequency counter may require as much as 250ma of current when all digits are illuminated it was designed as a bench instrument complete with a regulated power supply as described later. The transformer used was retrieved from an ancient digital alarm clock . Although a clocking signal could have been derived from the AC supply line , a digital clock oscillator was incorporated into the design to accommodate a battery pack supply instead of an AC supply source as an alternative. .

Following the design application of the Digital Capacitance Meter , the digital display read out section needed to be expanded by adding a second set of three

digits for a total of six digits to accomplish my goal of being able to count up to 1 Mhz without adding many stages of frequency division .
Once this accomplished I decided to increase the capability by adding one dividing stage to obtain a reading up to 12 Mhz and this was accomplished by adding only on IC and one switching stage .
You can make a search and download application data sheets for all the IC's used in this project from Motorola

The circuit

- In addition to the six digits counter circuit for display , the measurement of a frequency can be achieved with only four additional CMOS IC's ,MC or CD4521, 2 - MC or CD4093 and one MC or CD4017 . The six digits counter is made of two CMOS IC's MC14553 and two MC or CD14543 , six common Cathode digital displays and a few other parts . A complete list of parts is provided .

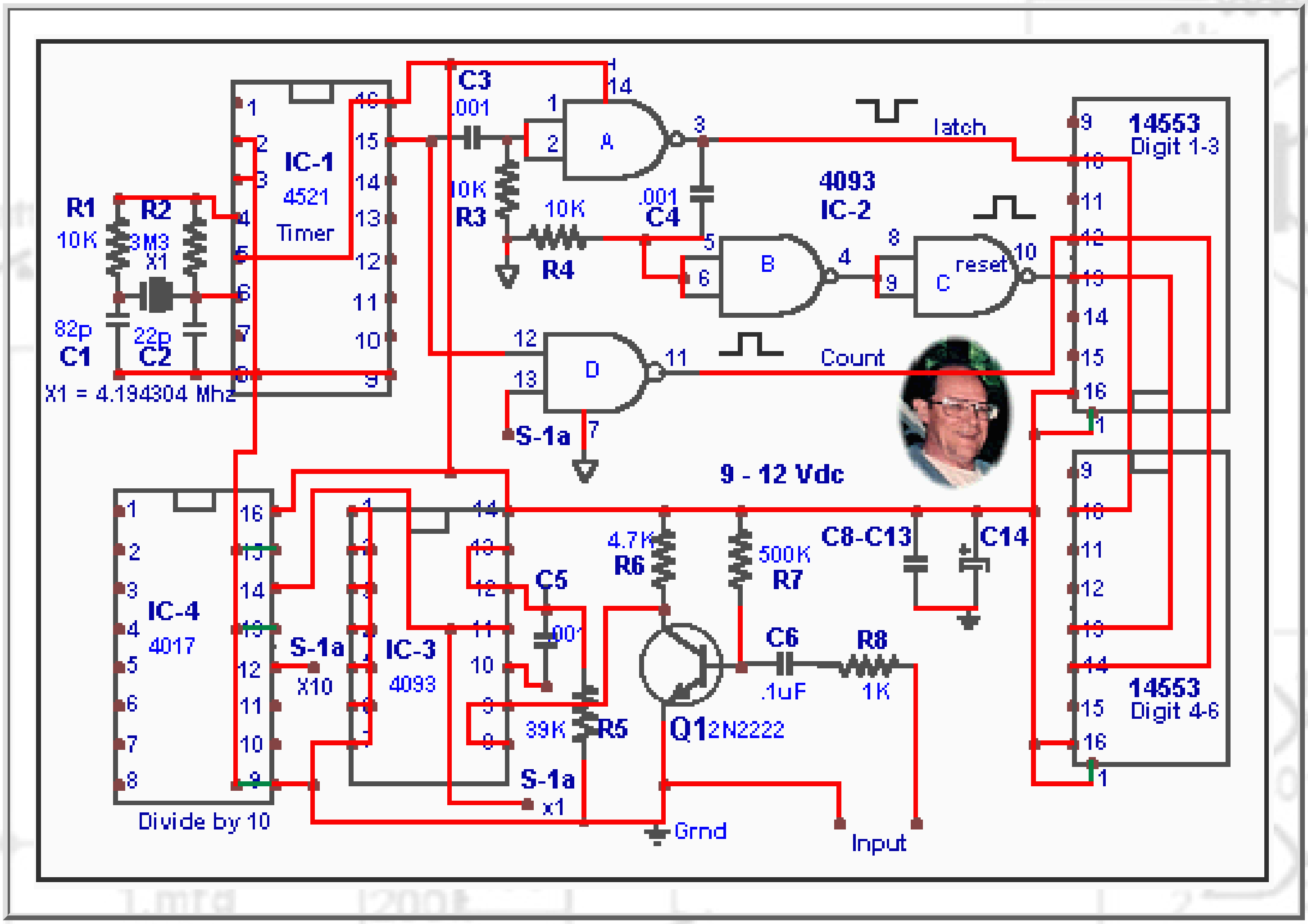
Logic Circuit Description

As a reference you may wish to open up a new window to view the circuit while reading the description.(The window size is adjustable)

- **The logic circuit is designed to accomplish the following ;**

a) Condition the input stage to accept a sine, square, pulse or triangle signal.
b) Amplify a weak signal voltage to a level required for good processing.
c) Attenuate any high level signal to a pre-determined level so as not to overload the permissible logic input voltage level .
d) Shape most frequency signals to be acceptable by the counter section for stable processing .
e) Provide for a timing sequence interval to enable the counter to accumulate a total count that accurately reflects the frequency being measured.

The input is fed to Q1 through R8 . Q1 is configured to amplify or attenuate the input signal and delivers a square wave from its collector output to pins 8 and 9 of IC-3 then this square wave is shaped into a pulse by two of the four gates available of IC-3 circuit , R5 and C5 also form part of that shaping circuit which is similar to the one shown in more details for IC-2 .
The output of IC-3 is taken from pin 11 and its one output is all that is require for a maximum count of 999,999 hertz which in this case can be connected directly to IC-2 gate D pin 13.



To obtain a count of more than 1 MHz, IC-4 CMOS 4017 is added to enable us to count up to 12 MHz which is the maximum operating frequency of IC-4 .The output of IC-3 from pin 11 is also sent to IC-4 pin 14 , IC-4 is used as a frequency divider and is configured to divide any frequency by 10 , thus for a given frequency of 10 MHz the counter will register and display 100,000.
Switch S1 is used to select the output of either IC-3 for a maximum count of MHz (999,999) or the output of IC-4 for a count of up to 12 MHz which in this case would be displayed as 120,000 .

The selected output is fed to the input of gate D of IC-2 as mentioned earlier , IC-2 is used to shape all the input signals required by the three digit counters CMOS MC14553 described below .
In order to be able to provide timing pulses to the counter an oscillator is required , IC-1 CMOS 4521 with its appropriate crystal (see parts list - xtal) delivers a one (1) pulse per second taken from pin 15 and is delivered to pin 1 & 2 of gate A and pin 12 of gate D of IC-2 .

As we can see IC-2 and IC-3 are used with the combination of C3,C4,C5,R3,R4 ,R5 to condition and invert the pulses where required to the counter as it requires exact timing and pulses shape for the stable operation of the counter.

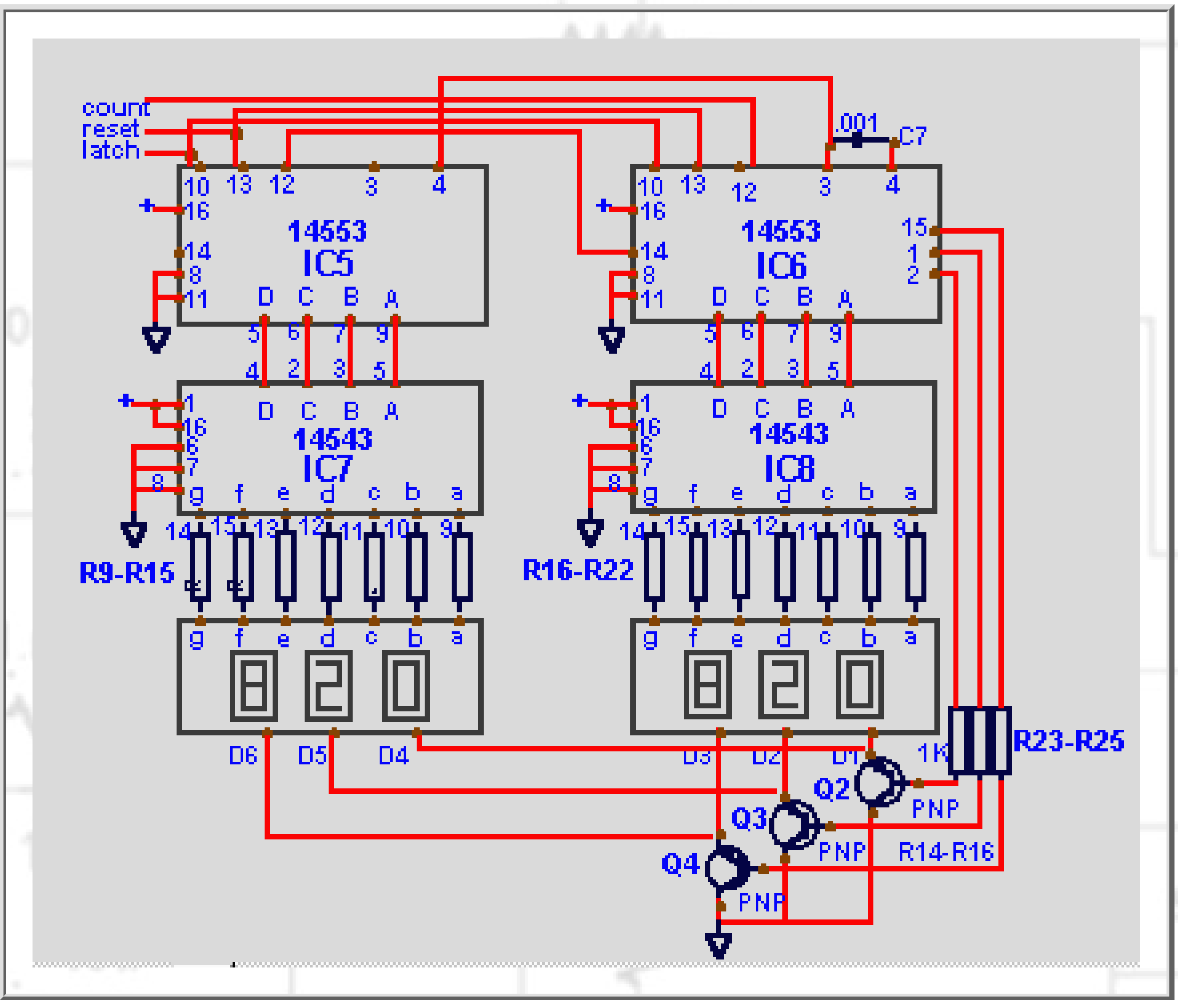
The Counter Display

As a reference you may wish to open up a new window to view the circuit while reading the description.(The window size is adjustable)

We need to know how the counter display operates in order to make use of it , the heart of the counter is the MC14553 which is a three-digit BCD counter and with the use of the MC14543 a BCD-to-seven segment decoder / driver will decode and activate the proper digit segments to display a maximum display count of 999.

To do this the MC14553 needs three input signals, a positive (high) pulse to the Latch input (pin #10) to enable storage of pulses to be stored into the latch and a Reset (pin # 13) pulse (high) to reset the counter . The total count desired is controlled by the Latch action which sets the time we require to insert the amount of pulses to the Counter (pin #12) to be displayed.

When the latch is high the count starts and when the Latch is low (zero) the count is stopped and the total of pulses accumulated in the latch are displayed then a positive pulse is required to the Reset to clear the Latch , the speed of this process is controlled by an internal 100 kHz oscillator which is determined by the .001 capacitor C7 connected between pin # 3 and pin # 4 of IC-6 .



To display six (6) digit we simply add an exact duplicate of the three digit circuit and connect the overflow from pin 14 of IC-6 to pin 12 of IC-5 as well as carry the oscillator signal from pin 3 of IC-6 to pin 4 of IC-5 and duplicate the inputs of the "

Count, Reset, Latch " as well.
Notice that only one set of driving transistors of three is still used but they are now connected to the second set of digit as well BUT the segment connections of each three digit must be kept separate and connected to its dedicated digit driver IC-7 and IC-8 as shown.

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Parts list

Circuit Parts list	
R1,R3,R4 = 10K R2 = 3.3 meg R5 = 39K R6 = 4.7K R8, R23 - R25 = 1K R9 - R22 = 180.0 (see text)	C1 = 82 pF C2 = 22 pF C3,C4,C5,C7 = .001 uF C6, C8 - C12 = 0.1 uF Polyester X1 = Crystal Freq. 4.194304 MHz
IC1 = CD4521 24 stage frequency divider IC2, IC3 = CD4093 , Quad " NAND " Schmitt trigger IC4 = CD4017 Decade counter/divider IC5,IC6 = MC14553 (Motorola) 3-digit BCD counter IC7,IC8 = CD4543 Digit driver Q1 = NPN 2N2222 or similar Q2 - Q4 = PNP 2N3906 or similar 6 each LED displays , Common cathode (see text) S1 = Miniature Toggle switch DPDT Center OFF (see text) Jack = 2 each , input ,banana type	

Construction

- This project may be not suitable for the beginners as a certain amount of experience is required to achieve a good operating system , nevertheless the following construction suggestions should help everyone in preventing most problems .

- Unless you never make mistakes use sockets for all the IC's.
- Keep all leads especially capacitor leads as short as physically possible.

- Best operating voltage is a regulated 9 volts DC supply .
- Use two 14 pins IC socket for R9 to R22 for quick adjustments . No need to mess up the PC .
- If and external power supply is used AC or DC install a regulator as well as a large filtering capacitor (1000 uF) for stability.
- The transistors used can be any general purpose PNP small signal transistors similar to the one listed but pins layout is to be taken in consideration to fit the PCB if used .
- The switch S1 is a miniature DP3P with Center OFF . As it is used to apply power to the circuit as well as signal range selection -it must be rated at 120v/3A . See illustrated application with power supply section .
- The following will produce noise ; bad capacitors , poor wiring, cold solder , bad connections , noisy supply lines , dirty switch contacts .

LED Displays

- The circuit was designed to use Common Cathode LED displays which I already had in my junk box . Any size and colour can be used as long as you can get the right colour filter for their use.

Important Note : For common cathode Pins 6 of the two 14543 ICs (IC-7 and IC-8) must be connected to the negative bus by bridging with a bit of solder to pins 7and 8 of each IC.

Using common anode display

The design can easily be modified for the use of Common Anode LED displays as follows ; (please refer to the Circuit layout)

1 - Still using PNP transistors , reverse their polarity so that the collector is now connected to digits 1 to 6 , the base connections remain the same as connected to the 1K resistors and the emitter will now be connected to the positive bus by doing the changes described in para **2**.
2 - Remove Jumper 1 (J1) and relocate and solder C13 in its place , install a jumper J2 at C13 former position . The transistors emitter are now connected to the positive instead of the negative bus .
3 -Install jumpers J3a and J3b from pin 6 of the 14543 IC's (IC-7 and IC-8) to the positive bus as shown .

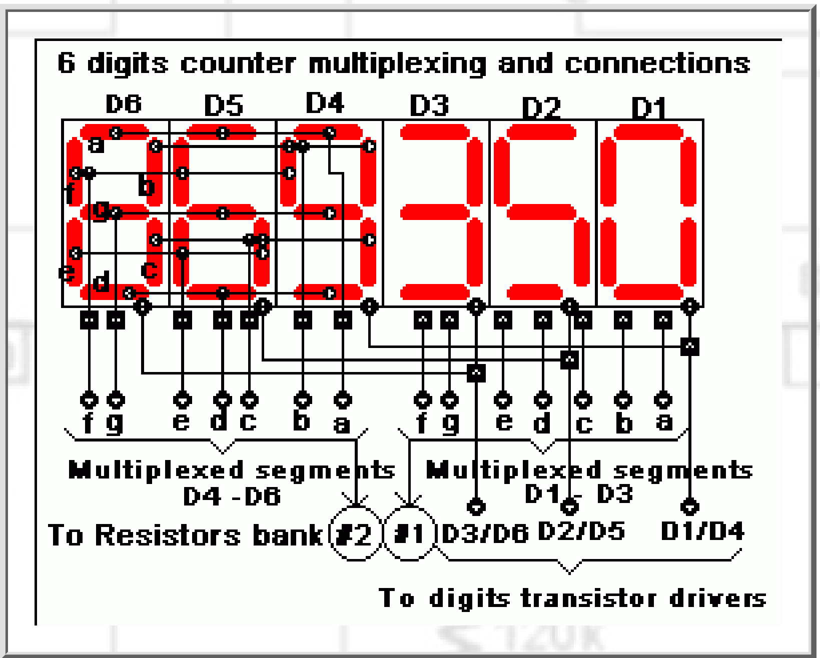
R9 to R22 are the segments current limiting resistors connected in series from the segment drivers IC-7 and; 8 . A maximum current of 10 ma per segment is recommended for long operating life of the LED displays , a 180 to 200 ohm resistor per segment should be used and can be increased in value as long as the brightness is acceptable thus saving on the current supply source .

To ease the burden of connecting that many resistors I used two 14 pins Dip sockets as shown in the PC layout section and installed two 7 x 181 ohm isolated

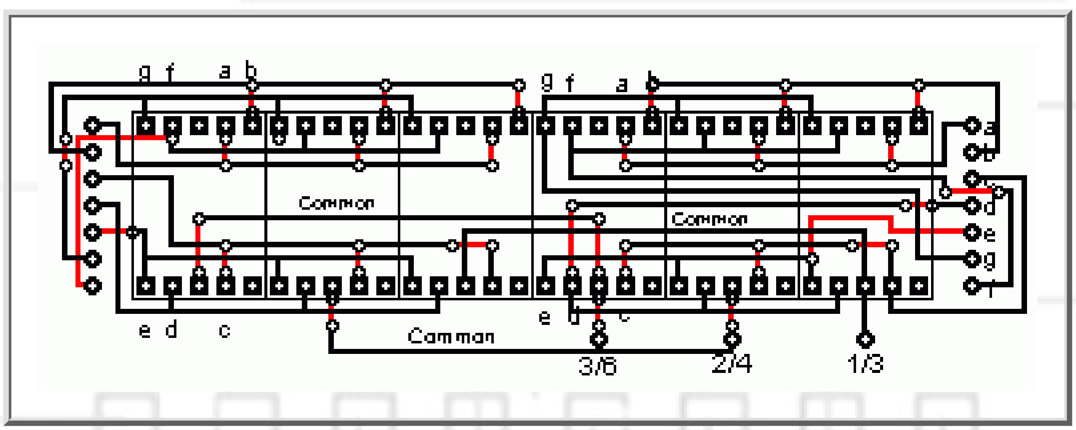
resistance Dip (called SIP ,see parts list) This leaves you the option for easy adjustment of the brightness by substitution if required later depending on the LED displays that you use.

Display

Shown below is a description of multiplexing the six LED digit displays . You will notice that two sets of three displays segments are interconnected and that the six digit common anodes or cathodes are connected in two set of three digits as shown to be controlled by the three digit select transistors .

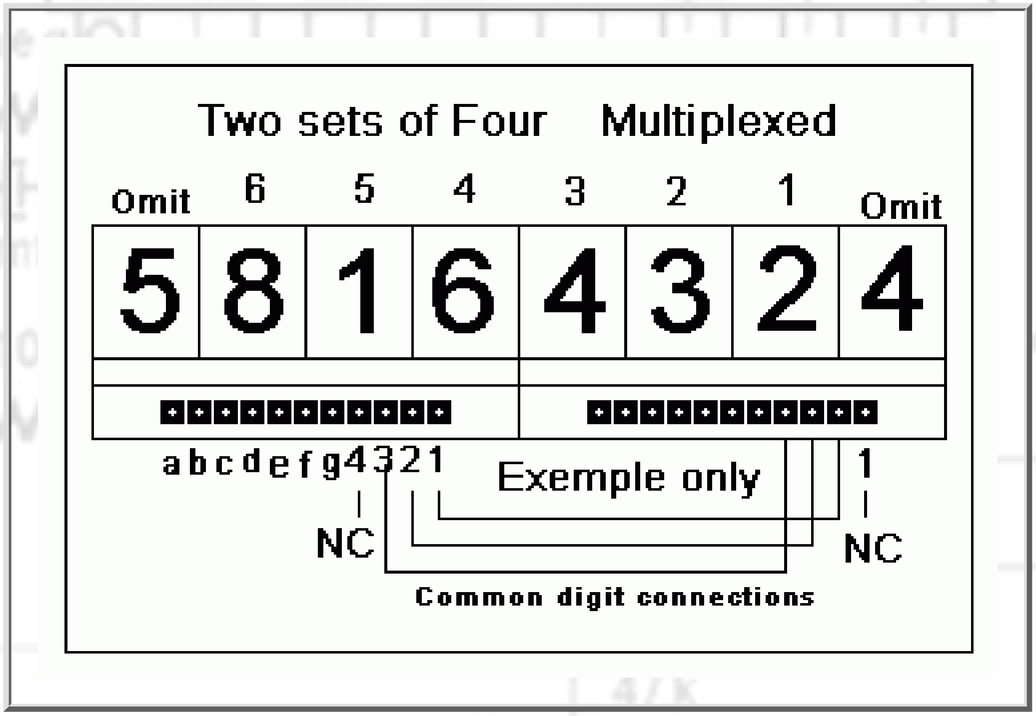


Example of single (with jumpers in red) or double layer PCB for six digits , size .56" common anode , standard pin layout .



Because of the pins arrangement of some digit display it is sometime difficult to do a proper job of interconnecting , for that reason you might be able to locate already multiplexed modules (Sticks) of three or four digits that you can use . If three are hard to find four digit modules are readily available for a slightly higher price and can be used by omitting connection to the first and last digit of each module when set end to end therefore using only the six center digits . From this point it is a

simple task of interconnecting the common pins as required .



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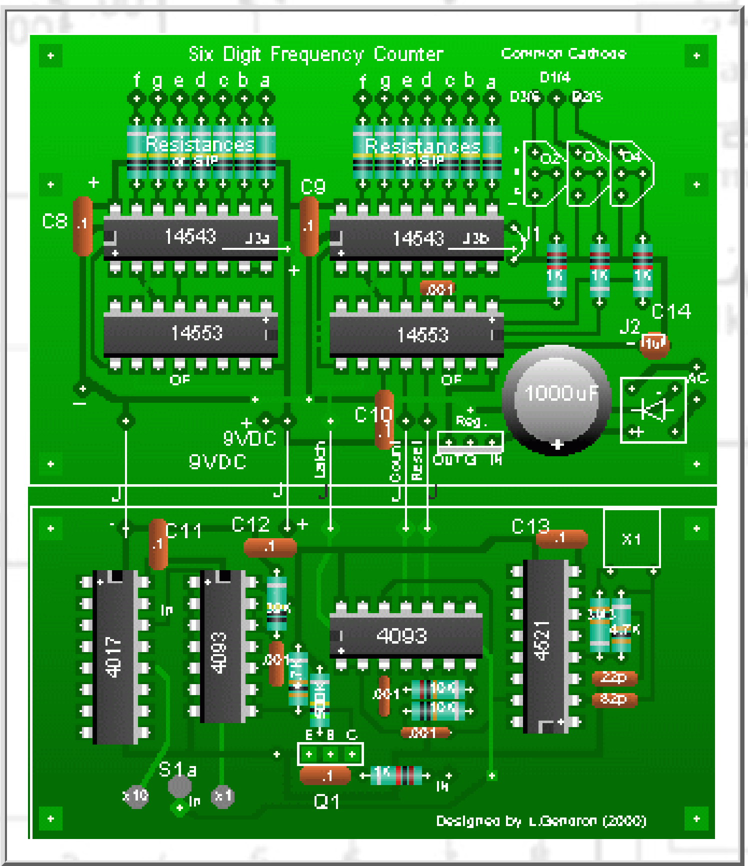
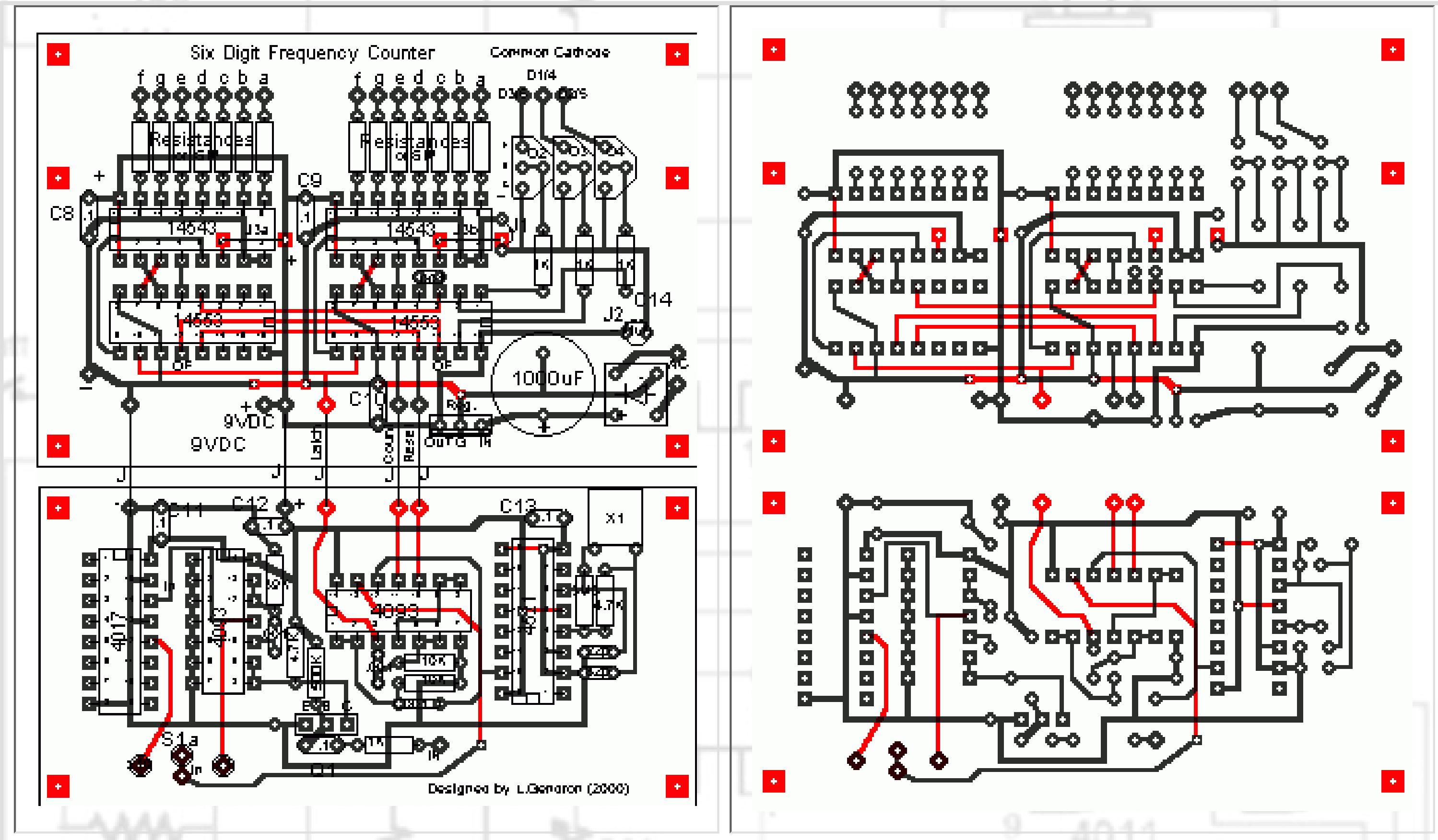
PCB Layout

Below is the layout for the six digit frequency counter . The layout reflects the designed circuit for common cathode displays with details of parts and jumpers as indicated for modifications as described preciously for the use of common anode displays .

The PCB has been designed into two separate PC boards that can be easily connected with jumpers or short wires . This to allow for a flexible installation at will in a small enclosure . On the other hand a single board can be made that would require a larger surface area and larger enclosure .



The upper part is the digital display circuitry and the lower part is the input and signal conditioning .



For the experienced hobbyists point to point wiring is quite possible using No 24 and smaller gauge wire , for a single layer board it is essential that all jumpers shown in red be installed before parts and sockets are soldered into place . For jumpers under the socket I use bared wrapping wire inserted in the wholes leaving about 1/4 " of wire produting on the solder side then fit the sockets into place then soldered all points.

Care must be taken to locate the transistors polarity for common cathode or common anode operation as explained previously . Take note that C13 is a polarized capacitor and oriented to suit the supply polarity if modified . (ref ; C13 and jumpers J1, J2 ,J3a&b)

The design will accept 14 pins Dip sockets in lieu of the 14 current limiting resistors allowing for the installation of SIP isolated resistors ICs or individual resistors with leads cut and shaped to fit the sockets for easy modification if required .

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6 Digit Frequency Counter

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Power Supply .

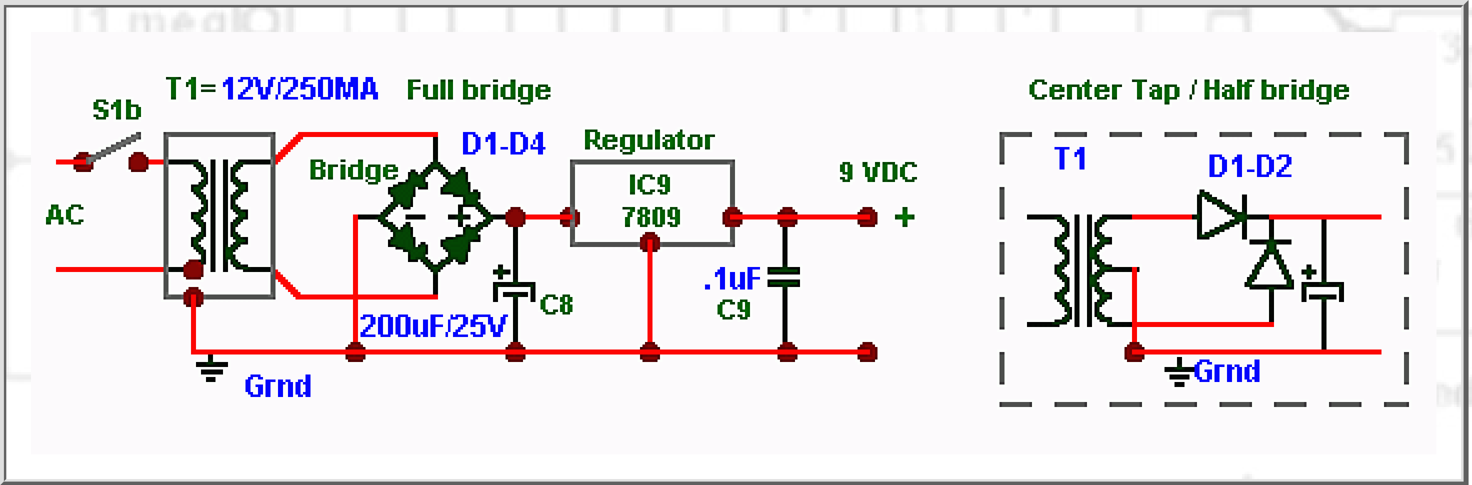
- Because of the low current requirement of most my designs, I usually prefer 9 volts as a convenient voltage supply source and for that reason the frequency counter has also been peaked for that voltage .

Below is the schematic for the power supply used as bench instrument and the parts list required . For stability and precision it is important that the power source be regulated and I have used a 9 volts regulator for a 12 volts power transformer source . The system will work well with a higher voltage supply with the following considerations ;

- The supply voltage must be at least 2 volts higher than the regulator voltage when under full load .
- The current limiting resistors value of R9 to R22 must be increased to limit the segments LED current within the 10 mA range .

- A battery pack can be used but again a regulator should be used so that the system does not suffer degradation due to battery voltage drop . A battery voltage monitor as described in the Digital Capacitance Meter project can used to monitor the battery voltage drop and set to about 1.5 volts above the regulator voltage as an indicator of low battery voltage .

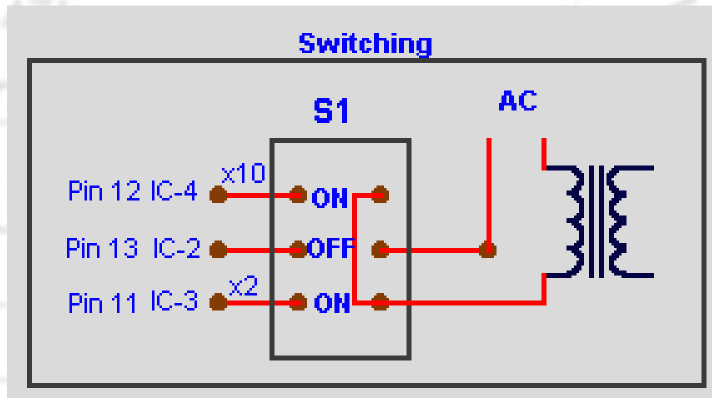
- As an option a wall transformer module can be used . Most wall transformer units are NOT well filtered and care must be taken to identify the voltage polarity of the output connection plug . Whether you use an AC or DC wall unit it is strongly recommended that the portion for the power supply circuit after the transformer , that is from the rectifier bridge and after be used to insure of the right voltage polarity and filtering .



Power Supply Parts List

Power supply parts list

Transformer = 120VAC to 12 V @ 250MA
Rectifier bridge 50V/1A
C8 = 200uF/25V
C9 = 0.1 uF /16V
Regulator = 7809 (9V) TO220 /1.5 A
Optional , D1 - D4 = Rectifier diodes 1N4002
Line cord , enclosure , insulating grommet



Suggestions

Select an enclosure large enough to accommodate the circuit and the transformer . I had a spare plastic box the size of which was perfect measuring 5"W x 3"H x 6"L .
I obtained the transformer from an old digital alarm clock from Sally Ann , the older the better as they all have a small 18 to 24 volts center tap transformer at about 300 mA .

A box with a plastic face panel is best as it is easy to cut a window to accommodate the six digit read-out covered with a thin red plastic as a filter as seen on my finished project , only the switch and two input plugs remain to be installed as shown . I used dry lettering transfers for the text covered with a light sprayed coat of clear lacker to protect the lettering from erasure .

Other than the switch ON/OFF with range selection there is no calibration required . A first check can be made by using a low voltage transformer with the primary connected to the AC line and measuring the 60Hz output on the low range of the Frequency Counter.

And please do not use the output of an AC outlet into your finished project for a test .

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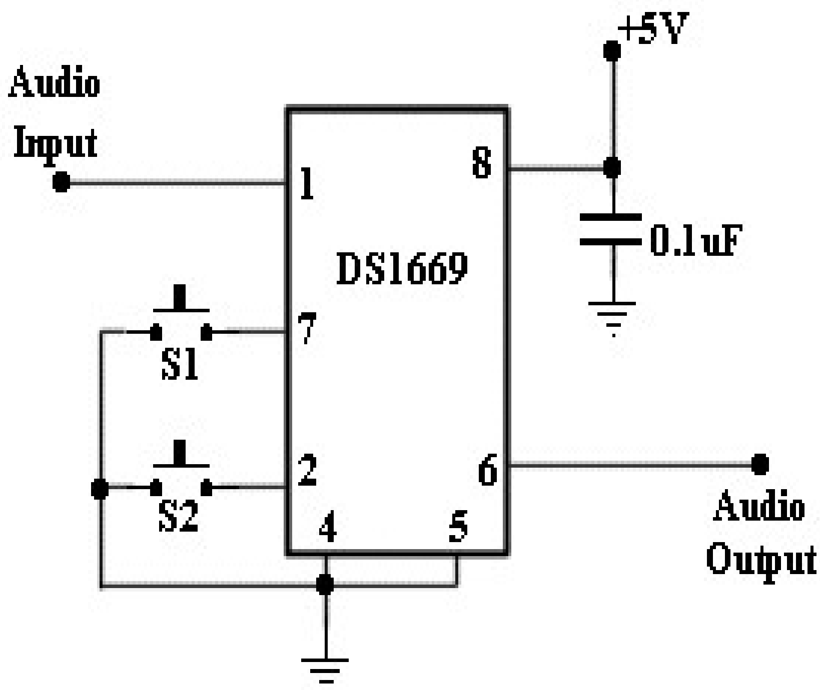
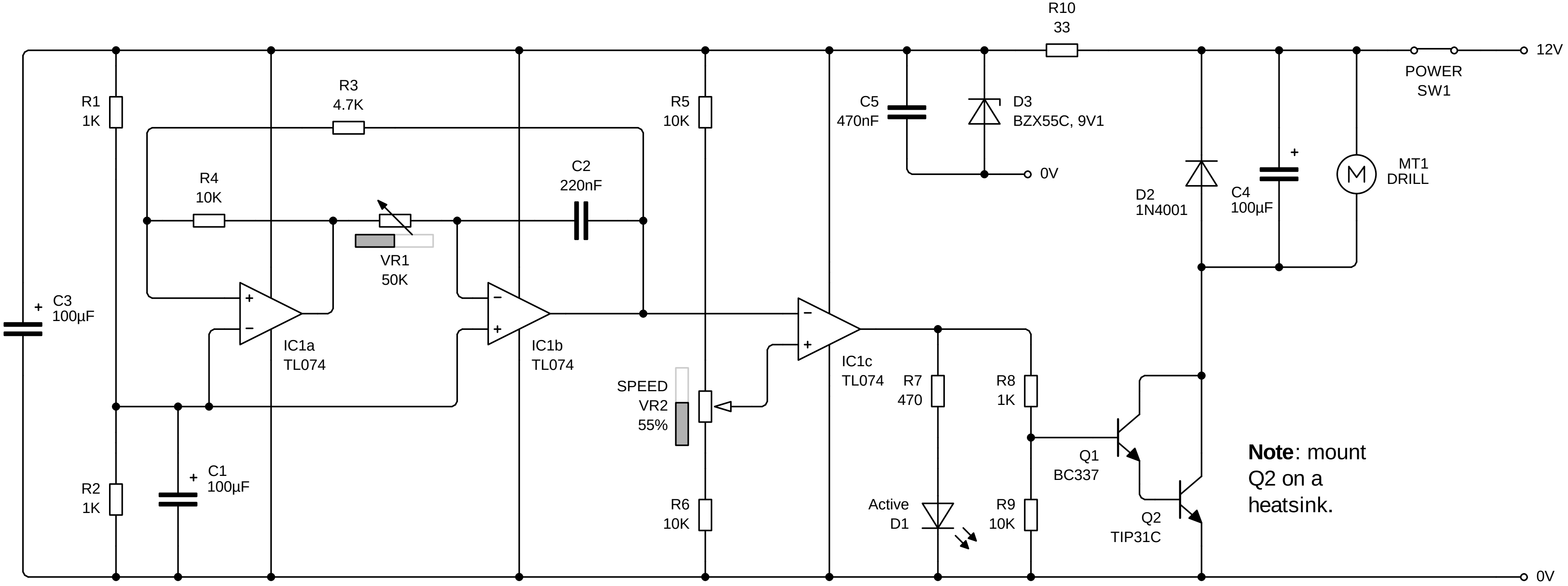
Digital Volume Control



This circuit could be used for replacing your manual volume control in a stereo amplifier. In this circuit, push-to-on switch S1 controls the forward (volume increase) operation of both channels while a similar switch S2 controls reverse (volume decrease) operation of both channels.

DRILL SPEED CONTROLLER

This circuit uses PWM to control the power delivered to a load, in this case a 12 PCB drill. It is based upon a triangle wave generator and comparator controlling the width and thus duty cycle of the output from 0-100%. The frequency is set using VR1 and is about 50Hz when in the midway position.

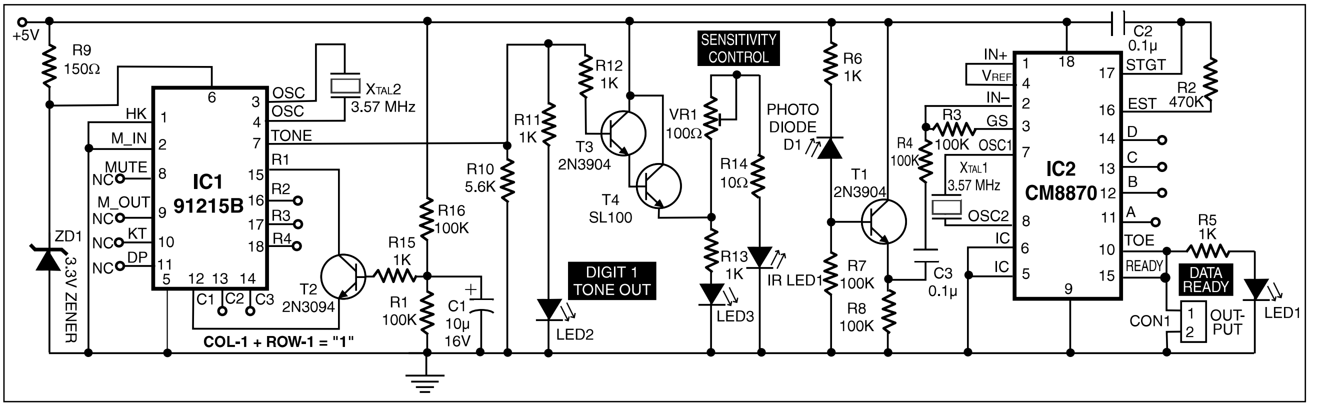


Note: mount Q2 on a heatsink.

DTMF PROXIMITY DETECTOR

K.S. SANKAR

A DTMF-based IR transmitter and receiver pair can be used to realise a proximity detector. The circuit presented here enables you to detect any object capable of reflecting the IR beam and moving in front of the IR LED photodetector pair up to a distance of about 12 cm from it.



The circuit uses the commonly available telephony ICs such as dial-tone generator 91214B/91215B (IC1) and DTMF decoder CM8870 (IC2) in conjunction with infrared LED (IR LED1), photodiode D1, and other components as shown in the figure. A properly regulated 5V DC power supply is required for operation of the circuit.

The transmitter part is configured around dialer IC1. Its row 1 (pin 15) and column 1 (pin 12) get connected together via transistor T2 after a power-on delay (determined by capacitor C1 and resistors R1 and R16 in the base circuit of the transistor) to generate DTMF tone (combination of 697 Hz and 1209 Hz) corresponding to keypad digit "1" continuously.

LED 2 is used to indicate the tone output from IC3. This tone output is amplified by Darlington transistor pair of T3 and T4 to drive IR LED1 via variable resistor VR1 in series with fixed 10-ohm resistor R14. Thus IR LED1 produces tone-modulated IR light. Variable resistor VR1 controls the emission level to vary the transmission range. LED 3 indicates that transmission is taking place.

A part of modulated IR light signal transmitted by IR LED1, after reflection from an object, falls on photodetector diode D1. (The photodetector is to be shielded from direct IR light transmission path of IR LED1 by using any opaque partition so that it receives only the reflected IR light.) On detection of the signal by photodetector, it is coupled to DTMF decoder IC2 through emitter-follower transistor T1.

When the valid tone pair is detected by the decoder, its StD pin 15 (shorted to TOE pin 10) goes 'high'. The detection of the object in proximity of IR transmitter-receiver combination is indicated by LED1. The active-high logic output pulse (terminated at connector CON1, in the figure) can be used to switch on/off any device (such as a siren via a latch and relay driver) or it can be used to clock a counter, etc.

This DTMF proximity detector finds applications in burglar alarms, object counter and tachometers, etc. ❑

Electronic Card-Lock System

VIJAY D. SATHE

The circuit presented here can be used as a lock for important electronic/electrical appliances. When card is inserted inside its mechanism, depending upon the position of punched hole on the card, a particular appliance would be switched on.

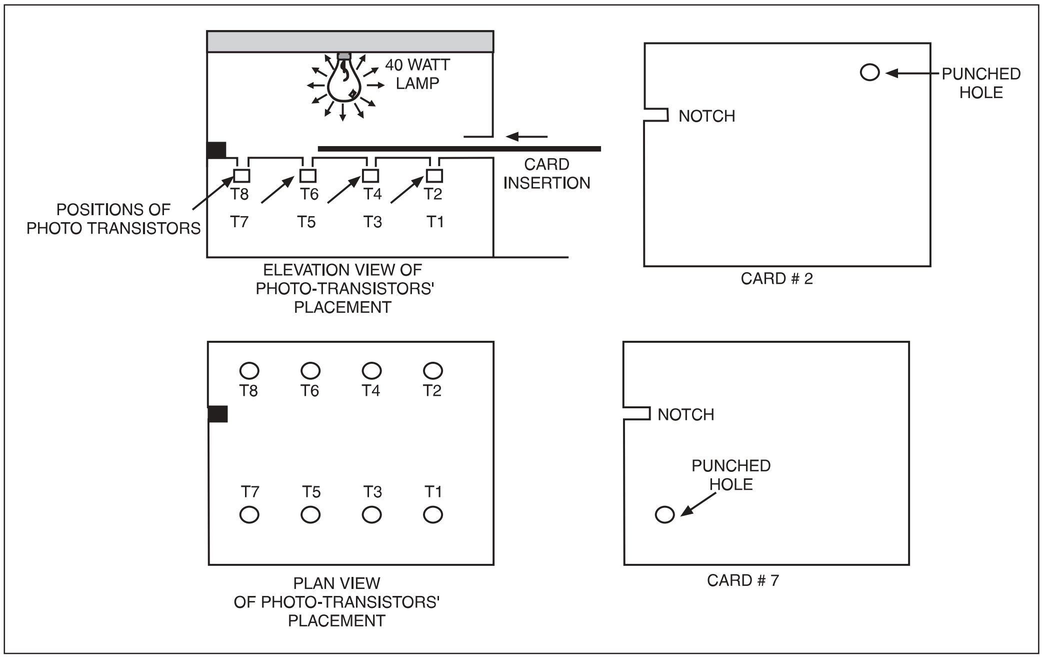
The card is inserted just like a floppy disk inside the disk drive. This card should be rectangular in shape with only one punched hole on it.

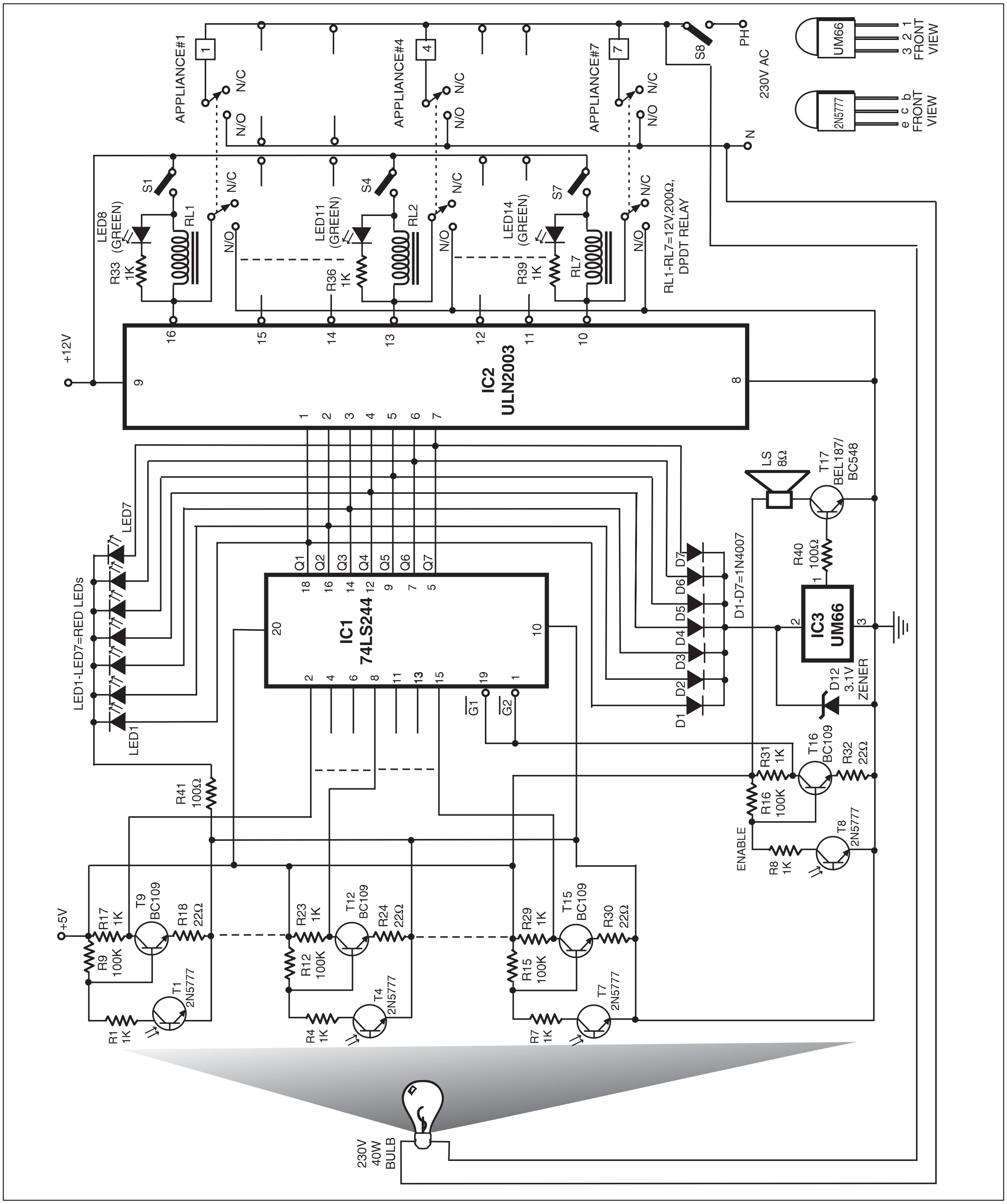
The circuit uses eight photo-transistors (T1 through T8). When there is no card in the lock, light from incandescent lamp L1 (40-watt, 230V) falls on all the photo- transistor detectors. Transistor T8 is used as enable detector for IC1 (74LS244). When light is incident on it, it conducts and its collector voltage goes low. This makes transistor T16 to cut-off, and its collector voltage goes high. This logic high on its collector terminal will inhibit IC1 as long as light is present on photo-transistor T8.

IC1 will get enabled only when the card is completely inserted inside the lock mechanism. This arrangement ensures that only the selected appliance is switched on and prevents false operation of the system.

You can make these cards using a black, opaque plastic sheet. A small rectangular notch is made on this card to indicate proper direction for insertion of the card. If an attempt is made to insert the card wrongly, it will not go completely inside the mechanism and the system will not be enabled.

When card for any appliance (say appliance 1) is completely inserted in the mechanism, the light will fall only on photo-transistor T1. So only T1 will be on and other photo-transistors will be in off state. When transistor T1 is on, its collector voltage falls, making transistor T9 to cut-off. As a result, collector voltage of transistor T9 as also pin 2 of IC1 go logic high. This causes pin 18 (output Q1) also to go high, switching LED1 on. Simultaneously, output Q1 is connected to pin 1 of IC2 (ULN2003) for driving the relay corresponding to appliance 1. Similarly, if card for appliance 2 is inserted, only output pin 16 (Q2) of IC1 will go high—making LED2 on while at the same time energising re-





lay for appliance 2 via ULN2003. The same is true for other cases/appliances also.

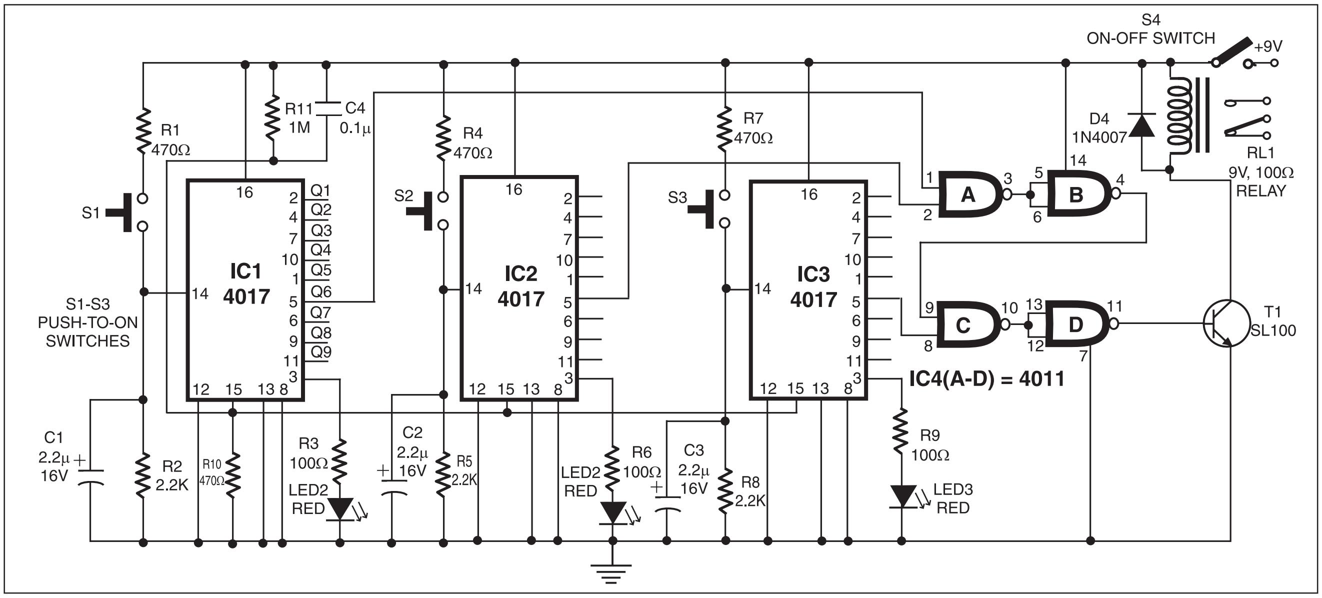
The time during which card is present inside the mechanism, the system generates musical tone. This is achieved with the help of diodes D1 through D7 which provide a wired-OR connection at their common-cathode junction. When any of the outputs of IC1 is logic high, the common-cathode junction of diodes D1 through D7 also goes logic high, enabling IC3 (UM66) to generate a musical tone.

In this circuit IC1 (74LS244) is used as buffer with Schmitt trigger. All outputs (Q1 through Q7) of this IC are connected

ELECTRONIC NUMBER LOCK

VYJESH M.V

The number lock described here works like a suitcase lock to some extent. This circuit can be adopted for any electronic gadget like VCR, TV or computer in conjunction with a relay.



The relay will operate only if the correct number is selected. For example, suppose the circuit is wired for number 666. To open the lock, switches S 1, S2 and S3 must be pushed six times each. The lock can be wired to operate with any number from 111 to 999 by simply changing the output tapping points of IC1 to IC3 from Q1 to Q9 respectively.

The circuit shown here is wired for number 666. In the circuit Q6 (pin 5) output of IC1, IC2 and IC3 have been connected to three inputs of 2-input NAND gates of a single IC 4011 (IC4) which contains four 2-input NAND gates. When pins 5 of IC1, IC2 and IC3 are logic high, the output pin 11 of the 'D' NAND gate also goes high, which in turn switches transistor T1 into conduction and the relay gets activated. LEDs 1, 2 and 3 are used to indicate that IC1, IC2 and IC3 are reset. The number lock should not be operated if all the three LEDs do not glow initially when switch S4 is put on. If the three LEDs do not glow, then press the on/off-cum-reset switch S4 again to reset IC1, IC2 and IC3. In the circuit diagram PIN 15 of all 4017s is connected to an R-C circuit (R10, R11 & C4) which will reset all 4017s as soon as power is switched on.

The number can be operated in any sequence by taking one's own time. For example, the number 666 can be selected by pressing S1, S2 and S3 three times and again S1, S2 and S3 another three times. Use of good quality, press-to-on switches is recommended to avoid false triggering. The circuit given here is for three digits. By increasing the number of 4017s the number of digits can be increased by using the same logic as given in this circuit idea.

ELECTRONIC SECURITY SYSTEM

S.C. DWIVEDI

K. BHARATHAN

This reliable and easy-to-operate electronic security system can be used in banks, factories, commercial establishments, houses, etc.

The system comprises a monitoring system and several sensing zones. Each sensing zone is provided with a closed-loop switch known as sense switch. Sense switches are fixed on the doors of premises under security and connected to the monitoring system. As long as the doors are closed, sense switches are also closed. The monitoring system can be installed at a convenient central place for easy operation.

Fig. 1 shows the monitoring circuit only for zone 1 along with the common alarm circuit. For other zones, the monitoring circuit is identical, with only the prefixes of components changing as per zone number. Encircled points A, B, and C of each zone monitoring circuit need to be joined to the corresponding points of the alarm circuit (upper half of Fig. 1).

When zone 1 sensing switch S11, zone on/off slide switch S12, and system on/off switch S1 are all on, pnp transistor T12 reverse biases to go in cut-off condition, with its collector at around 0 volt. When the door fitted with sensor switch S11 is opened, transistor T12 gets forward biased and it conducts. Its collector voltage goes high, which forward biases transistor T10 via resistor R10 to turn it on. (Capacitor C10 serves as a filter capacitor.) As a result, the collector voltage of transistor T10 falls to forward bias transistor T11, which conducts and its collector voltage is sustained at a high level. Under this latched condition, sensor switch S11 and the state of transistor T12 have no effect. In this state, red LED11 of the zone remains lit.

Simultaneously, the high-level voltage from the collector of transistor T11 via diode D10 is applied to V_{DD} pin 5 of siren sound generator IC1 (UM3561) whose pin 2 is grounded. Resistor R3 connected across pins 7 and 8 of IC1 determines the frequency of the in-built oscillator. As a result, IC1 starts generating the audio signal output at pin 3. The output voltage from IC1 is further amplified by Darlington pair of transistors T1 and T2. The amplified output of the Darlington pair drives the loudspeaker whose output volume can be controlled by potentiometer VR1. Capacitor C1 serves as a filter capacitor.

You can alter the alarm sound as desired by changing the connections of IC1 as shown in the table.

The circuit continues to sound the alarm until zone door is closed (to close switch S11) and the reset switch is pressed momentarily (which causes transistor T10 to cut off, returning the circuit to its initial state).

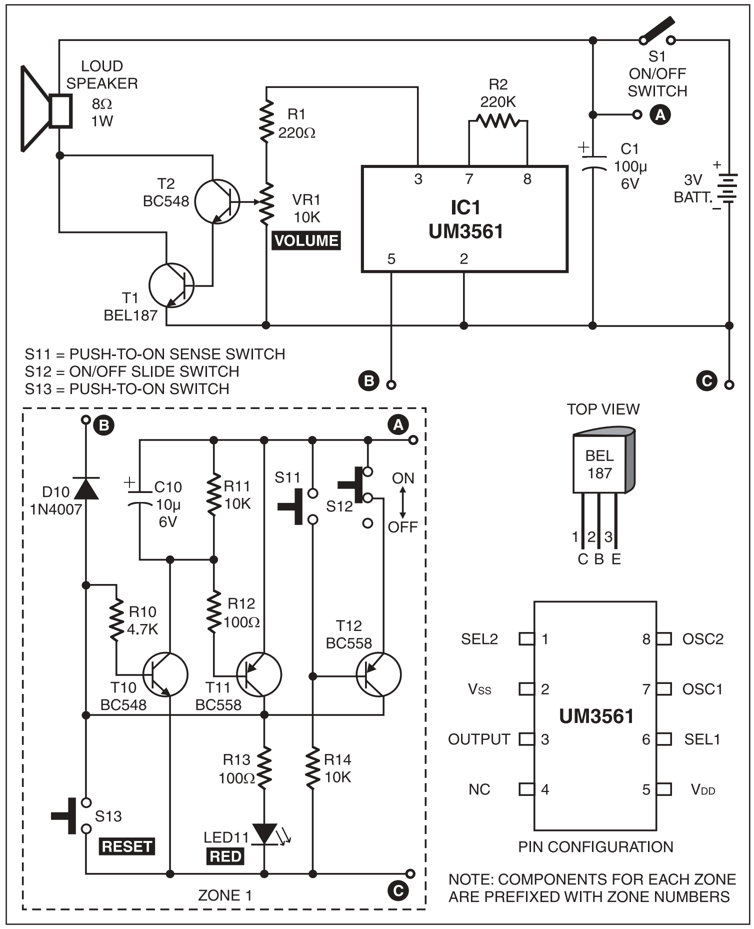


Fig. 1: Monitoring circuit along with the alarm circuit

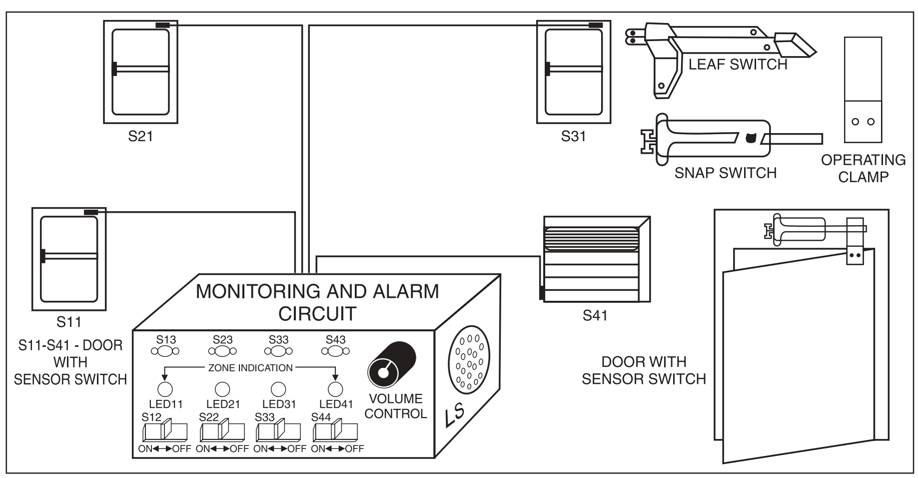


Fig. 2: Physical layout of sensors and monitoring/alarm system

The system operates off a 3V DC battery or recharging battery with charging circuit or battery eliminator. If desired, more operating zones can be added.

Alarm sound	Circuit connections	
	IC pin 1 connected to	IC pin 6 connected to
Police siren	NC	NC
Ambulance siren	NC	V_{DD}
Fire engine Sound	NC	V_{SS}
Machinegun sound	V_{SS}	NC

Note. *NC indicates no connection*

Initially keep the monitoring system switch S1 off. Keep all the zone doors fixed with sensing switches S11, S21, S31, S41, etc closed. This keeps the sensing switches for respective zones in closed position. Also keep zone slide switches S12, S22, S32, S42, etc in 'on' position. This puts the system in operation, guarding all the zone doors.

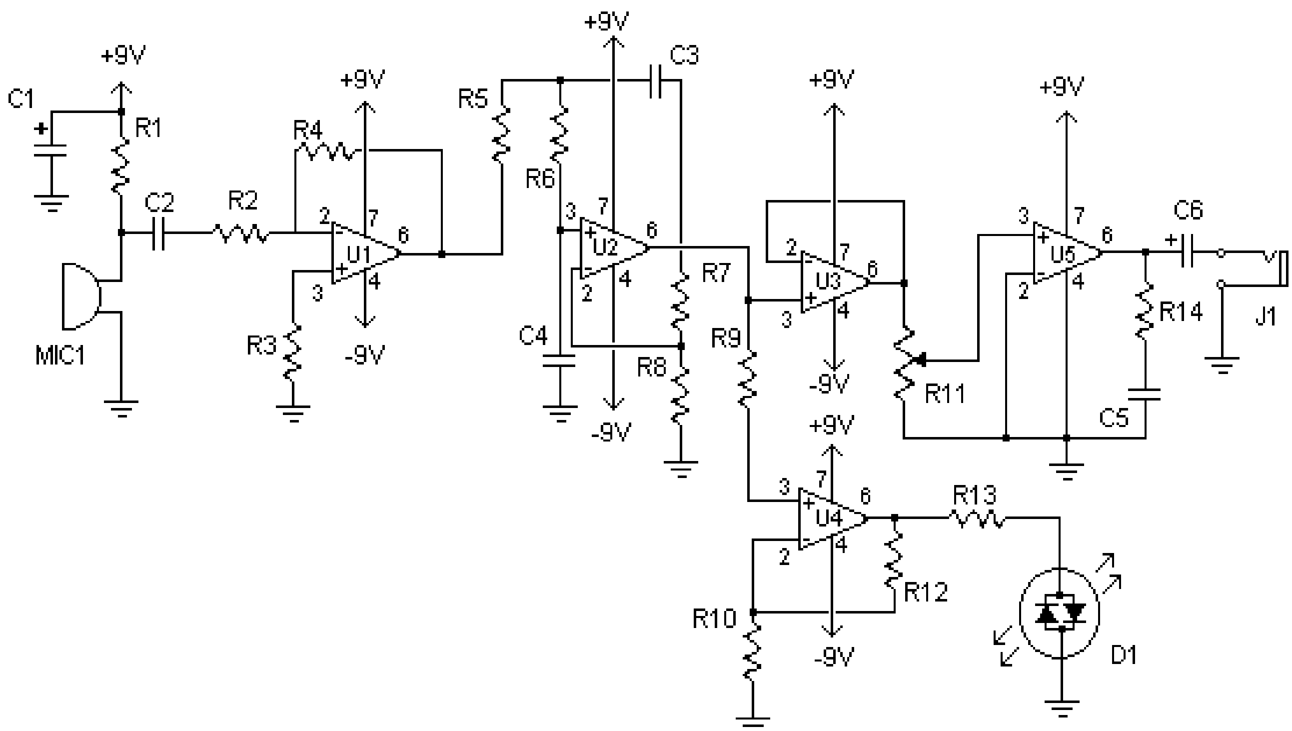
Now, if the door of a particular zone is opened, the monitoring system sounds an audible alarm and the LED corresponding to the zone glows to indicate that the door of the zone is open. The alarm and the LED indication will continue even after that particular door with the sensing switch is immediately closed, or even if that switch is removed/damaged or connecting wire is cut open.

Any particular zone in the monitoring system can be put to operation or out of operation by switching on or switching off the corresponding slide switch in the monitoring system.

The circuit for monitoring four zones costs around Rs 400.

Electronic Stethoscope

Stethoscopes are not only useful for doctors, but home mechanics, exterminators, spying and any number of other uses. Standard stethoscopes provide no amplification which limits their use. This circuit uses op-amps to greatly amplify a standard stethoscope, and includes a low pass filter to remove background noise.

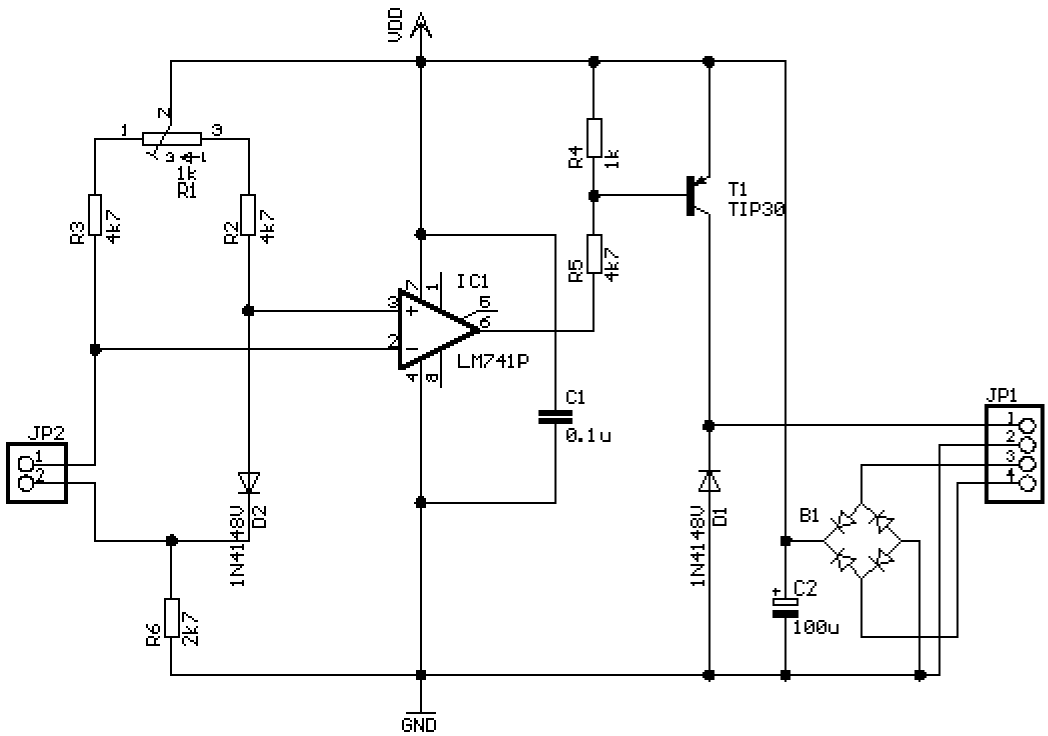


Note:

R1 - 10K 1/4W Resistor
R2, R3, R9 - 2.2K 1/4W Resistor
R4 - 47K 1/4W Resistor
R5, R6, R7 - 33K 1/4W Resistor
R8 - 56K 1/4W Resistor
R10 - 4.7K 1/4W Resistor
R11 - 2.5K Pot
R12 - 330K 1/4W Resistor
R13 - 1K 1/4W Resistor
R14 - 3.9 Ohm 1/4W Resistor
C1 - 470uF Electrolytic Capacitor

C2, C3, C4 - 0.047uF Capacitor
C5 - 0.1uF Capacitor
C6 - 1000uF Electrolytic Capacitor
D1 - Bi-Colour LED
U1, U2, U3, U4, U5 - 741 Op-Amp
MIC1 - Electret Mic
J1 - 1/4" Phone Jack
MISC - Board, Wire, Sockets for ICs, Knob for pot, Stethoscope, Rubber tube

Fan Controller



The amplifier gets quite hot while in use, so decided to use a fan to cool it. The fan, however, adds a lot of noise. To get the best of both worlds, I thought I'd turn the fan on only when required. The circuit shown uses two forward-biased diodes, one as a sensor diode (at JP2) and the other as a reference diode (D2). The small difference in forward voltage drop is amplified by IC1 and used to drive T1. T1 turns on a fan when the temperature on the reference diode exceeds that at D2. D1 prevents inductive kickback from killng T1. B1 and C2 provide a rectified, regulated supply from the transformer's auxiliary 12V winding. This prevents noise from the fan motor getting coupled to the rest of the amp.

R1 is used to adjust the temperature cutoff point. This is done by first adjusting it to remain permanently off (turn it both ways, whichever way causes it to turn off, turn it all the way there). Now let the amp run for a while at a reasonably loud volume, so that the output devices heat up. Now place the reference diode on the heatsink of the output devices and back down R1 until the fan just turns on. Make sure that the fan is positioned such that after a while, it cools down the output devices enough to turn itself off.

This and the next circuit are built on the same board, and use the same auxiliary 12V supply, to avoid loading the 78L12 and to prevent fan noise from being coupled into the amp.

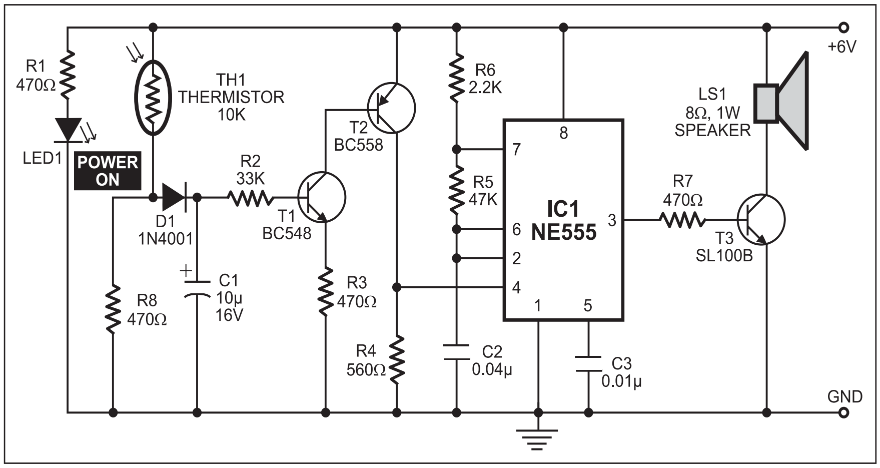
FIRE ALARM USING THERMISTOR

PRINCE PHILLIPS

In this fire alarm circuit, a thermistor works as the heat sensor. When temperature increases, its resistance decreases, and vice versa. At normal temperature, the resistance of the thermistor (TH1) is approximately 10 kilo-ohms, which reduces to a few ohms as the temperature increases beyond 100°C. The circuit uses readily available components and can be easily constructed on any general-purpose PCB.

Timer IC NE555 (IC1) is wired as an astable multivibrator oscillating in audio frequency band. Switching transistors T1 and T2 drive multivibrator NE555 (IC1). The output of IC1 is connected to npn transistor T3, which drives the loudspeaker (LS1) to generate sound. The frequency of IC1 depends on the values of resistors R5 and R6 and capacitor C2.

When thermistor TH1 becomes hot, it provides a low-resistance path to extend positive voltage to the base of transistor T1 via diode D1 and resistor R2. Capacitor C1 charges up to the positive voltage and increases the 'on' time of alarm. The higher the value of capacitor C1, the higher the forward voltage applied to the base of transistor T1 (BC548).



Since the collector of transistor T1 is connected to the base of transistor T2, transistor T2 provides positive voltage to reset pin 4 of IC1 (NE555). Resistor R4 is used such that IC1 remains inactive in the absence of positive voltage. Diode D1 stops discharging of capacitor C1 when the thermistor connected to the positive supply cools down and provides a high-resistance (10-kilo-ohm) path. It also stops the conduction of T1. To prevent the thermistor from melting, wrap it up in mica tape.

The circuit works off a 6V-12V regulated power supply. LED1 is used to indicate that power to the circuit is switched on.

DIY Kit 11. LONG LIFE FLASHER & CONTINUITY TESTER

Most integrated circuits are designed to operate in the 4V to 40V range. In particular most circuits to use indicator lights and LED's must be over 3V and even then the lifetime is not great.

The LM3909 introduced by National Semiconductor changed all this. Obtaining long life from a single 1.5V battery it opened up a whole new area of applications for linear IC's. Sufficient voltage for flashing a LED's is generated from a cell voltage as low as 1.1V. In such low duty cycle operation batteries can last for years.

Kit 11A is such a long life flasher. Powered by just a 1.5V D cell this very simple circuit will flash an LED for over 2 YEARS. It can provide the location of a piece of equipment in a darkened room. Placed in a car or around a window can act as an imitation alarm system.

Kit 11B uses the LM3909 as a simple continuity tester. The solid tone at zero ohms rapidly rises in pitch up to about 100 ohms whereupon it is not generated any more. Cut the wire with crocodile clips at both ends to use as the probes.

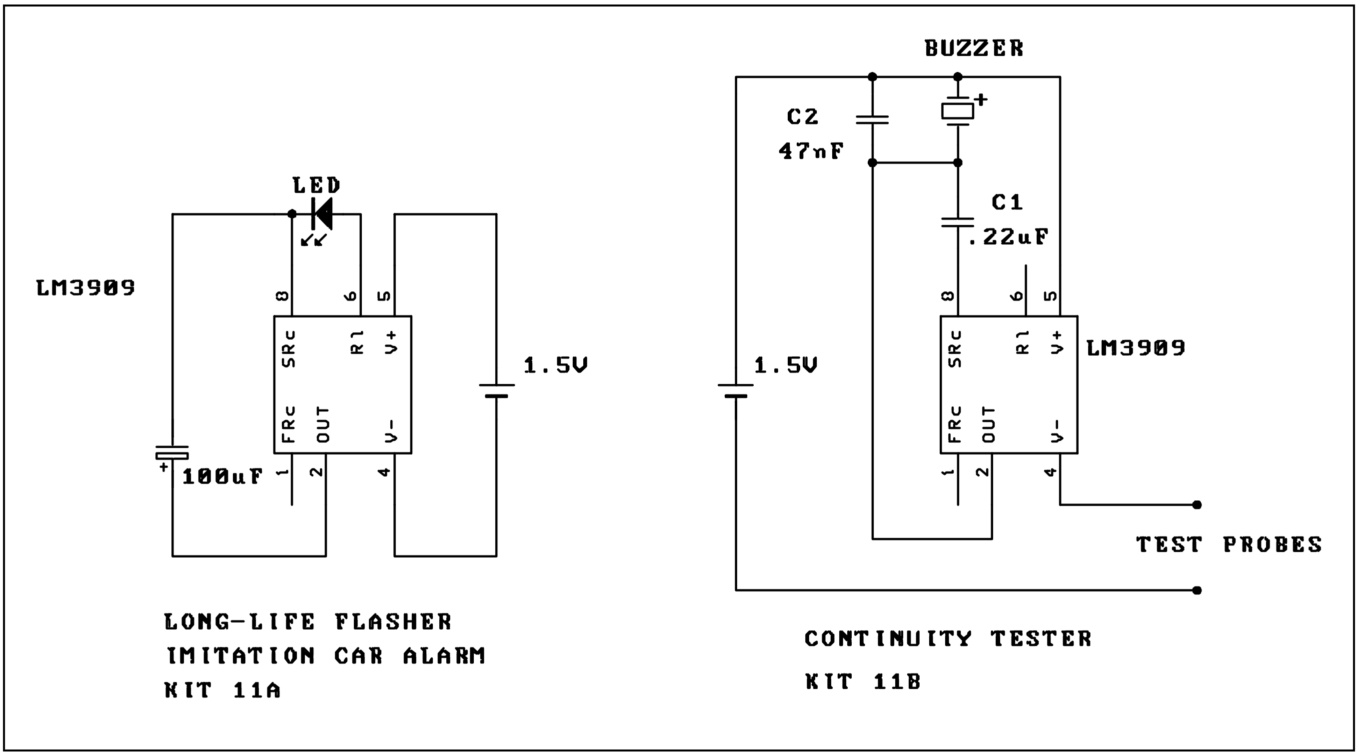
The kits are constructed on a single-sided printed circuit board (PCB). Protel Autotrax was used to design the board.

Download the Data Sheet and AN154 about the LM3909 from the National Semiconductor website at

www.national.com

Assembly is very straight forward. It is most unlikely that the Kits will not work immediately the battery is connected. If it does not work then check that the battery, LED and electrolytic capacitor are around the right way. Check all solder joints.Extra tie holes have been provided for securing the PCB to the battery leads. Only one LM3909 has been provided. Share it between both circuits.

COMPONENTS	
100uF ecap	1
5mm RED LED	1
LM3909 IC	1
8 pin IC socket	2
Kit 11A PCB	1
Kit 11B PCB	1
1.5V AA battery holders	2
Crocodile wire with clips	1
47nF 473 ceramic	1
0.22uF 224 ceramic	1
1.5V piezo buzzer with drive circuit	1



FLASHING-CUM-RUNNING LIGHT

A. SIVASUBRAMANIAN

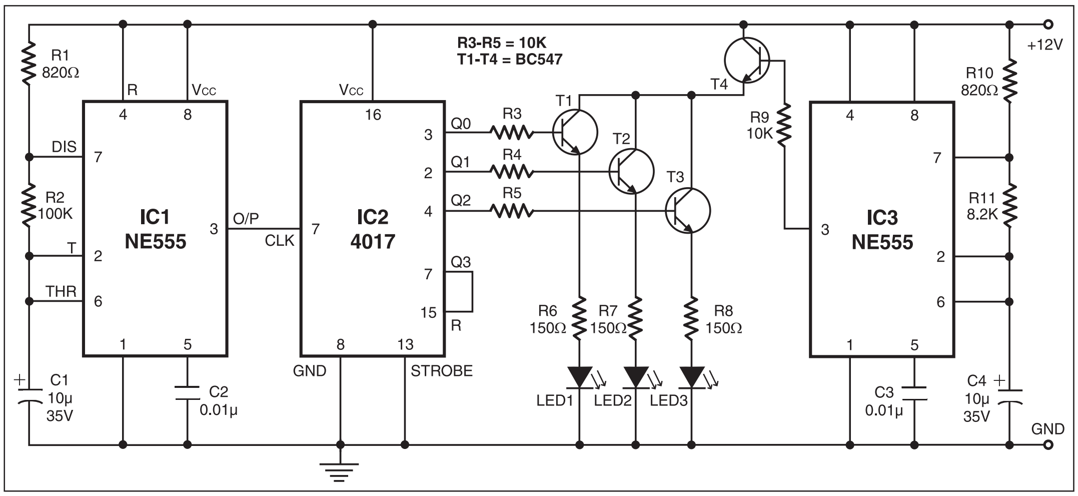
This circuit generates flashing lights in running pattern. In conventional running lights, the LEDs glow one by one. In this circuit, the LEDs flash a number of times one by one.

The circuit comprises two astable multivibrators (IC1 and IC3) and a decade counter (IC2). Astable multivibrator IC1 produces approximately 0.72Hz clock frequencies, which are given to decade counter IC2. The decade counter is designed to count Q0, Q1 and Q2 outputs, while its fourth output (Q3) is used to reset it. The Q0, Q1 and Q2 outputs of IC2 are fed to npn transistors T1, T2 and T3, respectively. The collectors of transistors T1, T2 and T3 are connected to the emitter of transistor T4, while their emitters are connected to LED1, LED2 and LED3 via 150-ohm resistors R6, R7 and R8, respectively. The LEDs are activated one by one by the decade counter outputs.

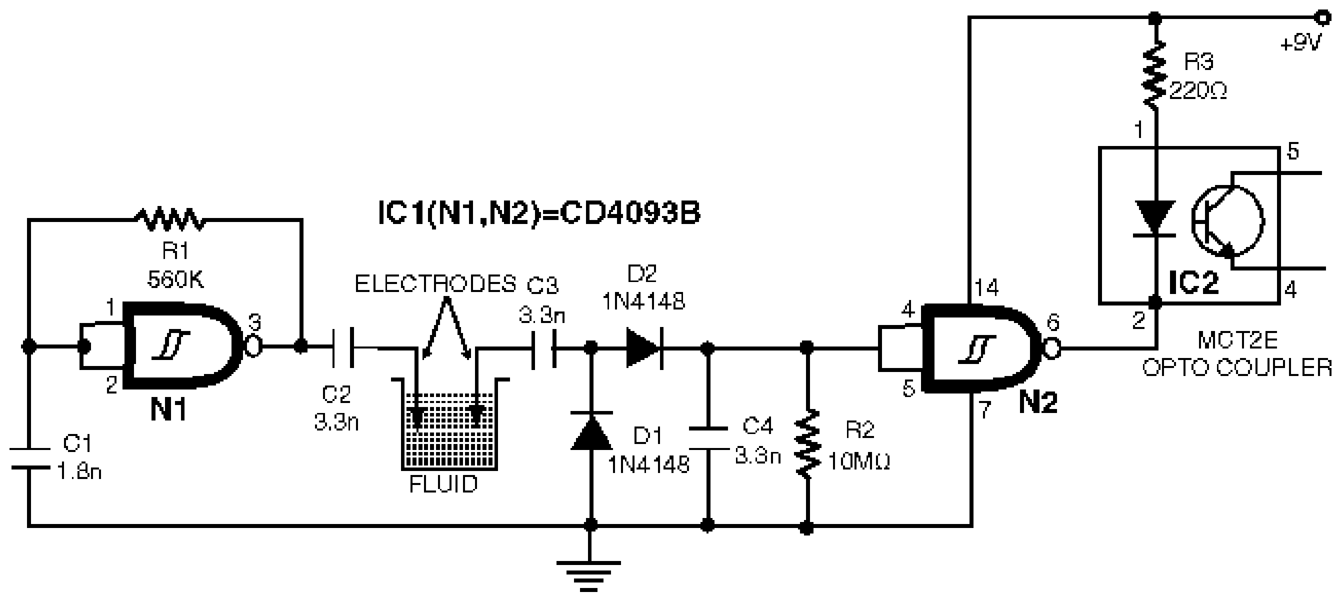
Astable multivibrator IC3 produces approximately 8.4Hz clock, which is given to transistor T4 via resistor R9 to switch on the supply to transistors T1 through T3 for each positive half cycle of IC3 output.

Now for each output period of IC2, a particular LED blinks at the rate of 8.4 Hz. The blinking then shifts to the next LED when the output of IC2 advances by one count (after about 1.3 seconds). Similarly, the blinking effect shifts to the next LED after another 1.3 seconds and the cycle repeats thereafter.

Flashing frequencies can be changed by changing the values of R10 and R11 and capacitor C4. The circuit can be easily assembled on any general-purpose PCB. It works off a 12V regulated power supply. You can also add more LEDs in series with LED1, LED2 and LED3, respectively.



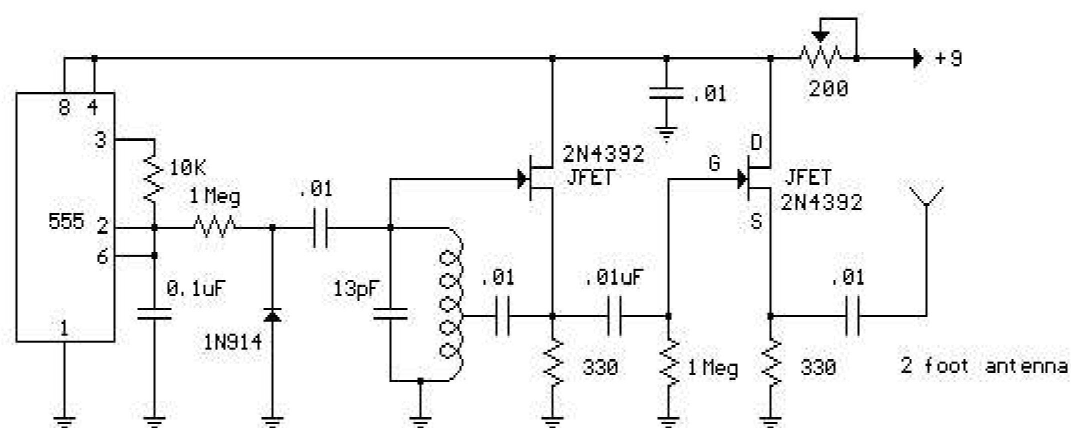
Fluid Level Detector



Here is a simple but versatile circuit of fluid level detector which can be used for various applications at home and in industry. Circuit is built around 2-input NAND Schmitt trigger gates N1 and N2. Gate N1 is configured as an oscillator operating at around 1 kHz frequency. When the fluid level reaches the probe's level, the oscillations are coupled to the diode detector stage comprising diodes D1 and D2, capacitor C4 and resistor R2. The positive voltage developed across capacitor C4 and resistor R2 combination is applied to Schmitt NAND gate N2 which is used here as a buffer/driver. The output of gate N2 is connected to opto-coupler MCT2E. The output across pins 4 and 5 of the opto-coupler can be suitably interfaced to any external circuit for indication purposes or driving any load as desired. Use of opto-coupler ensures complete isolation of the load from the fluid level detector circuit. Since high frequency AC is used for the electrodes, there is no corrosion of the electrodes which is normally observed with DC being applied to the electrodes.

FM Beacon Broadcast Transmitter (88-108 MHz)

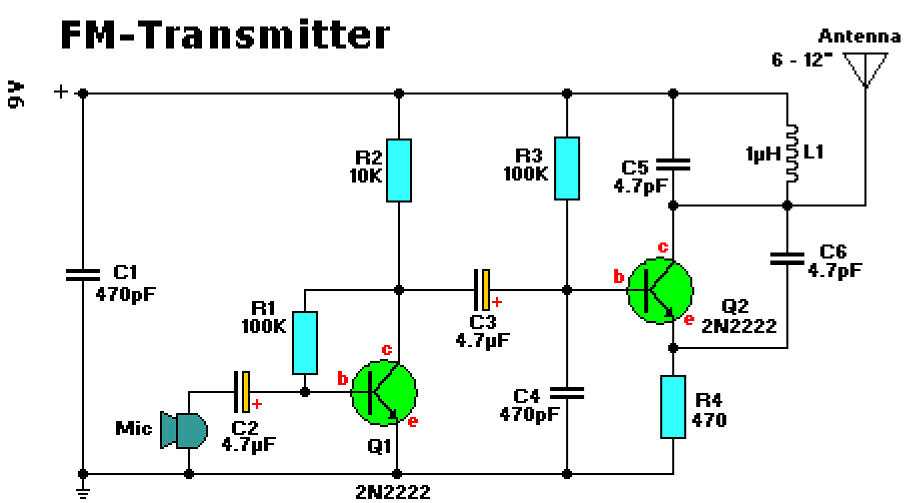
This circuit will transmit a continuous audio tone on the FM broadcast band (88-108 MHz) which could used for remote control or security purposes. Circuit draws about 30 mA from a 6-9 volt battery and can be received to about 100 yards. A 555 timer is used to produce the tone (about 600 Hz) which frequency modulates a Hartley oscillator. A second JFET transistor buffer stage is used to isolate the oscillator from the antenna so that the antenna position and length has less effect on the frequency. Fine frequency adjustment can be made by adjusting the 200 ohm resistor in series with the battery. Oscillator frequency is set by a 5 turn tapped inductor and 13 pF capacitor. The inductor was wound around a #8 X 32 bolt (about 3/16 diameter) and then removed by unscrewing the bolt. The inductor was then streached to about a 3/8 inch length and tapped near the center. The oscillator frequency should come out somewhere near the center of the band (98 MHz) and can be shifted higher or lower by slightly expanding or compressing the inductor. A small signal diode (1N914 or 1N4148) is used as a varactor diode so that the total capacity in parallel with the inductor varies slightly at the audio rate thus causing the oscillator frequency to change at the audio rate (600 Hz). The ramping waveform at pins 2 and 6 of the timer is applied to the reversed biased diode through a large (1 Meg) resistor so that the capacitance of the diode changes as the ramping voltage changes thus altering the frequency of the tank circuit. Alternately, an audio signal could be applied to the 1 Meg resistor to modulate the oscillator but it may require an additional pullup resistor to reverse bias the diode. The N channel JFET transistors used should be high frequency VHF or UHF types or similar.



FM - Transmitter

Nothing critical here. To get a bit of tuning out of the coil you could put a 4-40pF trimmer capacitor (optional) parallel over the 1 µH coil, L1.
C1/C4 and C5/C6 are ceramic capacitors, preferably NPO (low noise) types. C2/C3 are electrolytic or can be tantalum types.
The antenna is nothing more than a piece of 12" wire or a piece of piano wire from 6" to 12".

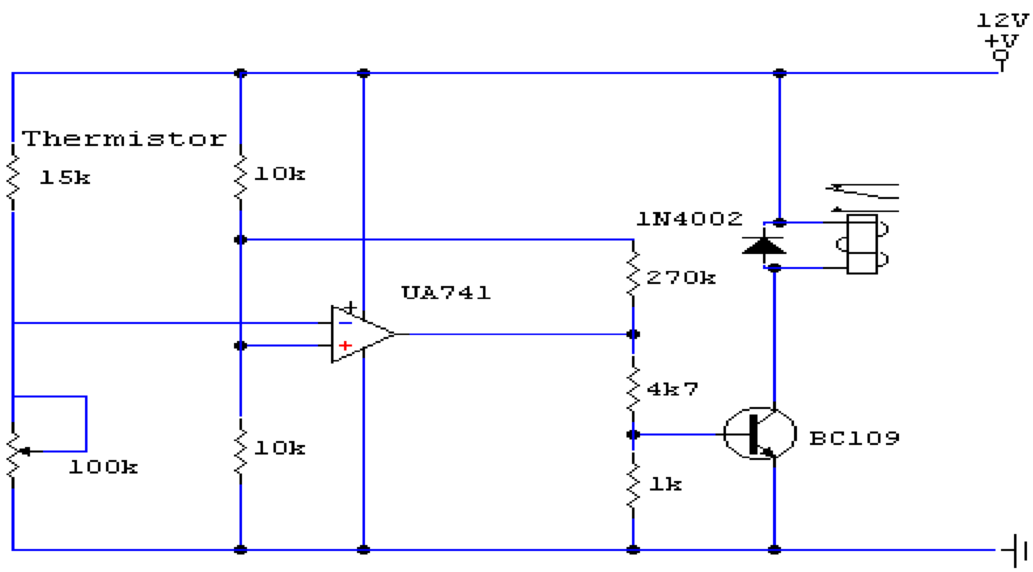
To find the signal on your receiver, make sure there is a signal coming into the microphone, otherwise the circuit won't work. I use an old mechanical alarm clock (you know, with those two large bells on it). I put this clock by the microphone which picks up the loud tick-tock. I'm sure you get the idea... Or you can just lightly tap the microphone while searching for the location of the signal on your receiver.



Parts List:

```
R1,R3 = 100K
   R2 = 10K
   R4 = 470 ohm
C1,C4 = 470pF
C2,C3 = 4.7µF, 16V, electrolytic
C5,C6 = 4.7pF
   C7 = 4-40pF trimmer cap (optional, see text)
   L1 = 1µH
Q1,Q2 = 2N2222, NPN transistor
  Mic = Electret Microphone
   B1 = 9 Volt, Alkaline battery
```

Frost Alarm



The thermistor used has a resistance of 15k at 25 degrees and 45k at 0 degrees Celsius. A suitable bead type thermistor is used. The 100k pot allows this circuit to trigger over a wide range of temperatures. A slight amount of hysteresis is provided by inclusion of the 270k resistor. This prevents relay chatter when temperature is near the switching threshold of this circuit.

FUEL RESERVE INDICATOR FOR VEHICLES

EFY SANI THEO TESTED

■ D. MOHAN KUMAR

Here is a simple circuit for monitoring the fuel level in vehicles. It gives an audiovisual indication when the fuel level drops alarmingly below the reserve level, helping you to avoid running out of petrol on the way.

Nowadays vehicles come with a dash-mounted fuel gauge meter that indicates the fuel levels on an analogue display. The 'reserve' level is indicated by a red marking in some vehicles, but the needle movement through the red marking may be confusing and not precise. This circuit monitors the fuel tank below the reserve level and warns through LED indicators and audible beeps when the danger level is approaching.

The fuel sensor system consists of a tank-mounted float sensor and a current meter (fuel meter), which are connected in series. The float-driven sensor attached to an internal rheostat offers high resistance when the tank is empty. When the tank is full, the resistance decreases, allowing more current to pass through the meter to give a higher reading.

The fuel monitoring circuit works by sensing the voltage variation developed across the meter and activates the beeper when the fuel tank is almost empty. Its point A is connected to the input terminal of the fuel meter and point B is connected to the body of the vehicle.

The circuit consists of an op-amp IC CA3140 (IC1), two 555 timer ICs (IC2 and IC3) and decade counter CD4017 (IC4).

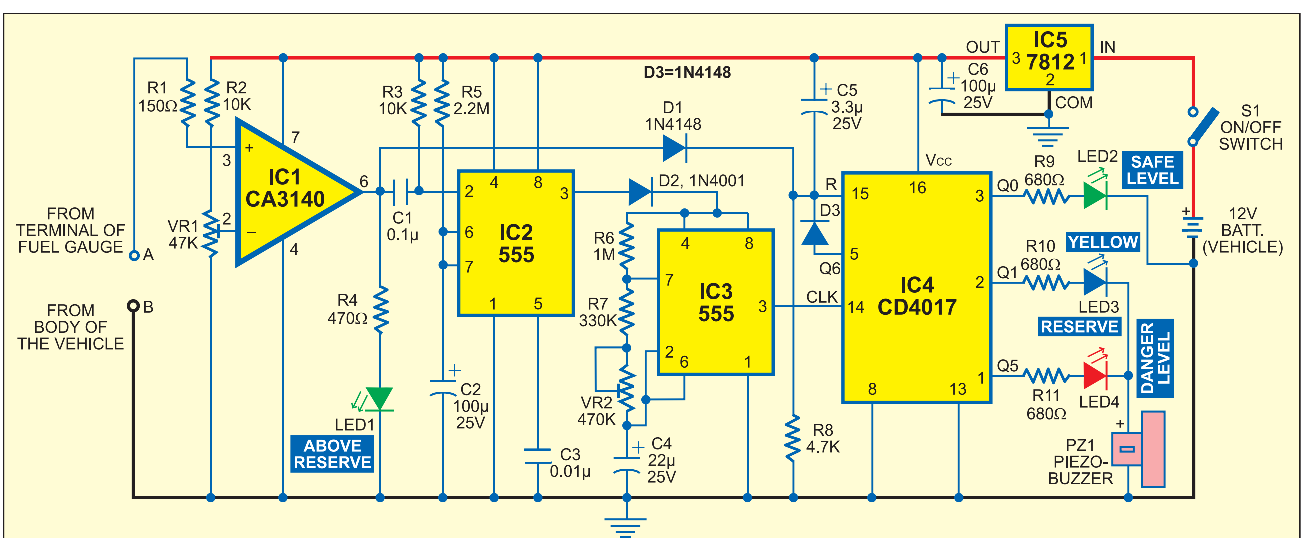
Op-amp IC CA3140 is wired as a voltage comparator. Its inverting input (pin 2) receives a reference voltage controlled through VR1. The non-inverting input (pin 3) receives a variable voltage tapped from the input terminal of the fuel meter through resistor R1.

When the voltage at pin 3 is higher than at pin 2, the output of IC1 goes high and the green LED (LED1) glows. This condition is maintained until the voltage at pin 3 drops below that at pin 2. When this happens, the output of IC1 swings from high to low, sending a low pulse to the trigger pin of the monostable (usually held high by R3) via C1. The monostable triggers and its output goes high for a predetermined time based on the values of R5 and C2. With the given values, the 'on' time will be around four minutes.

The output of IC2 is used to power the astable circuit consisting of timer 555 (IC3) via diode D2. Oscillations of IC3 are controlled by R6, R7, VR2 and C4. With the given values, the 'on' and 'off' time periods are 27 and 18 seconds, respectively. The pulses from IC3 are given to the clock input (pin 14) of decade counter CD4017 (IC4) and its outputs go high one by one.

When the circuit is switched on, LED1 and LED2 glow if your vehicle has sufficient petrol in the tank. When the fuel goes below the reserve level, the output of IC1 goes low, LED1 turns off and a negative triggering pulse is received at pin 2 of IC2. The output of IC2 goes high for around four minutes and during this time period, clock pin 14 of IC4 receives the clock pulse (low to high) from the output of IC3.

For the first clock pulse, Q0 output of IC4 goes high and the green LED (LED2) glows for around 50 seconds. On receiving the second clock pulse, Q1 goes high to light up the yellow LED (LED3) and sound the buzzer for around 45 seconds. This audio-visual signal warns you that the vehicle is running out of fuel. On receiving the



third clock pulse, LED3 and the buzzer go off. There is a gap of around two-and-a-half minutes before Q5 output goes high.

By the time Q5 goes high and the red LED (LED4) glows, four minutes elapse and the power supply to IC3 is cut off. The output state at Q5 will not change unless a low-to-high clock input is received at its pin 14. Thus LED4 will glow continuously along with the beep. The continuous glowing of the red LED (LED4) and the beep from the buzzer indicate that the vehicle will run out of fuel very shortly.

Q6 output of IC4 is connected to its reset pin 15 via diode D3. This means that after 'on' state of Q5, the count will always start from Q0. Capacitor C5 provides power-on reset to IC4 when switch S1 is closed. The output of IC1 is also connected to reset pin of IC4 via diode D1 (1N4148). So when your vehicle is refueled above the reserve level, LED2 glows to indicate that the tank has sufficient fuel.

IC5 provides regulated 12V DC for proper functioning of the circuit even when the battery is charged to more than 12V.

The circuit can be assembled on a perforated board**.** Adjust VR1 until the voltage at pin 2 of IC1 drops to 1.5V. When point A is connected to the fuel meter (fuel gauge) terminal that goes to the fuel sensor, green LEDs (LED1 and LED2) glow to indicate the normal fuel level. VR2 can be varied to set the 'on' time period of IC3 at around 20 seconds.

Enclose the circuit in a small case and mount on the dashboard using adhesive tape. The circuit works only in vehicles with negative grounding of the body. ●

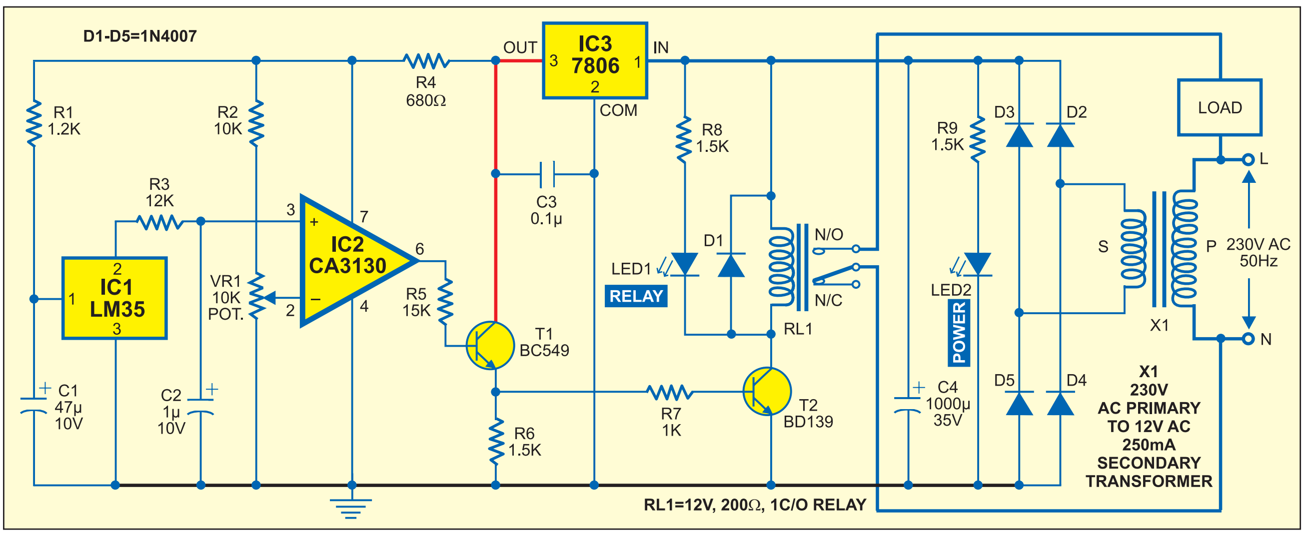
HEAT-SENSITIVE SWITCH

■ M.K. CHANDRA MOULEESWARAN AND MISS KALAI PRIYA

At the heart of this heat-sensitive switch is IC LM35 (IC1), which is a linear temperature sensor and linear temperature-to-voltage converter circuit.

The converter provides accurately linear and directly proportional output signal in millivolts over the temperature range of 0°C to 155°C. It develops an output voltage of 10 mV per degree centigrade change in the ambient temperature. Therefore the output voltage varies from 0 mV at 0°C to 1V at 100°C and any voltage measurement circuit connected across the output pins can read the temperature directly.

The input and ground pins of this heat-to-voltage converter IC are connected across the regulated power supply rails and decoupled by R1 and C1. Its temperature-tracking output is applied to the non-inverting input (pin 3) of the comparator built around IC2. The inverting input (pin 2) of IC2 is connected across the positive supply rails via a voltage divider network formed by potmeter VR1.



Since the wiper of potmeter VR1 is connected to the inverting input of IC2, the voltage presented to this pin is linearly variable. This voltage is used as the reference level for the comparator against the output supplied by IC1.

So if the non-inverting input of IC2 receives a voltage lower than the set level, its output goes low (approximately 650 mV). This low level is applied to the input of the load-relay driver comprising npn transistors T1 and T2. The low level presented at the base of transistor T1 keeps it non-conductive. Since T2 receives the forward bias voltage via the emitter of T1, it is also kept non-conductive. Hence, relay RL1 is in de-energised state, keeping mains supply to the load 'off' as long as the temperature at the sensor is low.

Conversely, if the non-inverting input receives a voltage higher than the set level, its output goes high (approximately 2200 mV) and the load is turned 'on.' This happens when IC1 is at a higher temperature and its output voltage is also higher than the set level at the inverting input of IC2. So the load is turned on as soon as the ambient temperature rises above the set level. Capacitor C3 at this pin helps iron out any ripple that passes through the positive supply rail to avoid errors in the circuit operation.

By adjusting potmeter VR1 and thereby varying the reference voltage level at the inverting input pin of IC1, the temperature threshold at which energisation of the relay is required can be set. As this setting is linear, the knob of potmeter VR1 can be provided with a linear dial caliberated in degrees centigrade. Therefore any temperature level can be selected and constantly monitored for external actions like turning on a room heater in winter or a room cooler in summer. The circuit can also be used to activate emergency fire extinguishers, if positioned at the probable fire accident site.

The circuit can be modified to operate any electrical appliance. In that case, relay RL1 must be a heavy-duty type with appropriately rated contacts to match the power demands of the load to be operated. ●

Infrared Cordless Headphone

PRADEEP G.

Using this low-cost project one can reproduce audio from TV without disturbing others. It does not use any wire connection between TV and headphones. In place of a pair of wires, it uses invisible infrared light to transmit audio signals from TV to headphones. Without using any lens, a range of up to 6 metres is possible. Range can be extended by using lenses and reflectors with IR sensors comprising transmitters and receivers.

IR transmitter uses two-stage transistor amplifier to drive two series-connected IR LEDs. An audio output transformer is used (in reverse) to couple audio output from TV to the IR transmitter. Transistors T1 and T2 amplify the audio signals received from TV through the audio transformer. Low-impedance output windings (lower gauge or thicker wires) are used for connection to TV side while high-impedance windings are connected to IR transmitter. This IR transmitter can be powered from a 9-volt mains adapter or battery. Red LED1 in transmitter circuit functions as a zener diode (0.65V) as well as supply-on indicator.

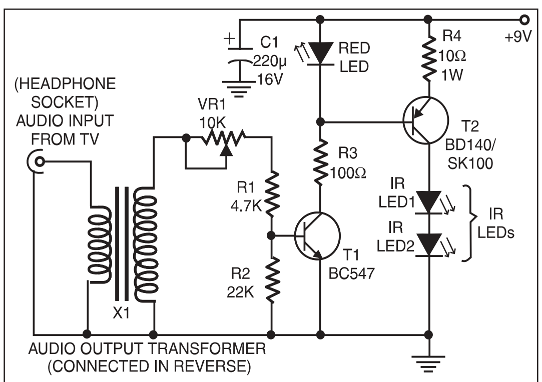


FIG.1: IR Audio Transmitter

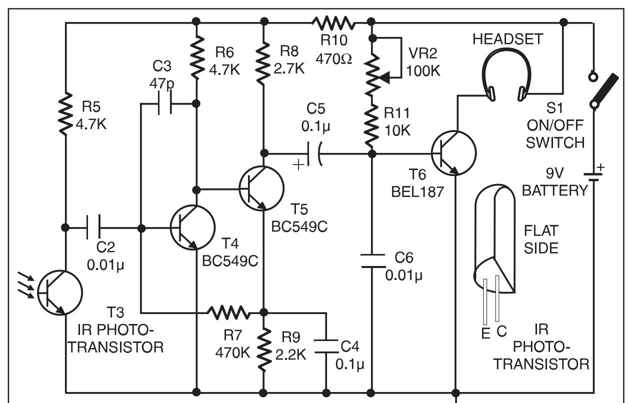


FIG.2: IR Audio Recieiver

IR receiver uses 3-stage transistor amplifier. The first two transistors (T4 and T5) form audio signal amplifier while the third transistor T6 is used to drive a headphone. Adjust potmeter VR2 for max. clarity.

Direct photo-transistor towards IR LEDs of transmitter for max. range. A 9-volt battery can be used with receiver for portable operation.

INFRARED TOY CAR MOTOR CONTROLLER

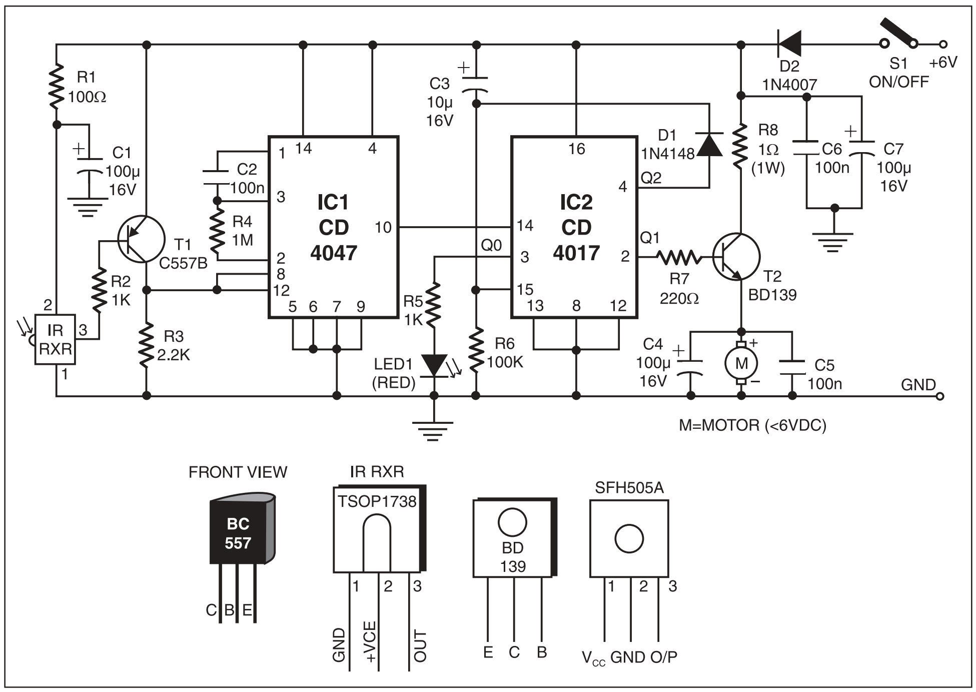
T.K. HAREENDRAN

This add-on circuit enables remote switching on/off of battery-operated toy cars with the help of a TV/video remote control handset operating at 30–40 kHz.

When the circuit is energised from a 6V battery, the decade counter CD4017 (IC2), which is configured as a toggle flip-flop, is immediately reset by the power-on-reset combination of capacitor C3 and resistor R6. LED1 connected to pin 3 (Q0) of IC2 via resistor R5 glows to indicate the standby condition. In standby condition, data output pin of the integrated infrared receiver/demodulator (SFH505A or TSOP1738) is at a high level (about 5 volts) and transistor T1 is 'off' (reverse biased). The monostable wired around IC1 is inactive in this condition.

When any key on the remote control handset is depressed, the output of the IR receiver momentarily transits through low state and transistor T1 conducts. As a result, the monostable is triggered and a short pulse is applied to the clock input (pin 14) of IC2, which takes Q1 output (pin 2) of IC2 high to switch on motor driver transistor T2 via base bias resistor R7 and the motor starts rotating continously (car starts running). Resistor R8 limits the starting current.

When any key on the handset is depressed again, the monostable is retriggered to reset decade counter IC2 and the motor is switched off. Standby LED1 glows again.



This circuit can be easily fabricated on a general-purpose printed board. After construction, enclose it inside the toy car and connect the supply wires to the battery of the toy car with right polarity. Rewire the DC motor connections and fix the IR receiver module in a suitable location, for example, behind the front glass, and connect its wires to the circuit board using a short 3-core ribbon cable/shielded wire.

Note. Since the circuit uses modulated infrared beam for control function, ambient light reflections will not affect the circuit operation. However, fluorescent tubelights with electronic ballasts and CFL lamps may cause malfunctioning of the circuit.

K92. IR Remote Control & Decoder IC

This Kit uses a commercial 14-pin remote control unit to put an active low signal onto one of 14 pins on a decoder IC. That is, when a RC button is pressed, the pin corresponding to that button on the decoder IC goes low. Normally, each of the 14 output pins is high. It is up to the user to use this information in their own circuit where remote control is required. For example, to control up to 14 relays or to control the movement of a robot. We supply all the necessary extra components required for the decoder IC to function properly. No PCB is supplied. It is up to the user to breadboard their application then make their own PCB. A sample application/test circuit is provided. A 330Ω resistor & LED are supplied for testing the active low on a pin in response to a button press.

We supply three sets of components:

1. a 14 button Infra Red Remote Control unit. It just needs you to add 2 x AAA batteries.
2. a 3-pin Infrared Receiver Module, the Waitrony PIC1018SCL which converts the modulated 38kHz signal into data pulses.
3. an Atmel 89C2051-24PC microcontroller which we have preprogrammed to decode the IR data pulses from the remote control into one of 14 active low outputs. All required components for the microcontroller are supplied – a 12MHz ceramic resonator for the oscillator, resistor, capacitor and diode for the power-on reset circuit plus two 10K pullup resistors (see below).

CIRCUIT DESCRIPTION

The remote control unit sends out a 38KHz signal modulated with data pulses for the particular button pressed. The infrared receiver module removes the 38KHz signal and outputs the data pulse stream. This is fed into the microcontroller where it is decoded by onboard firmware and one of the fourteen ouputs will go low. The microcontroller outputs are normally held high by internal pullups except for pins 12 and 13 which require external pullup resistors (10K).

DECODER IC PINOUTS

The following table lists each pin function.

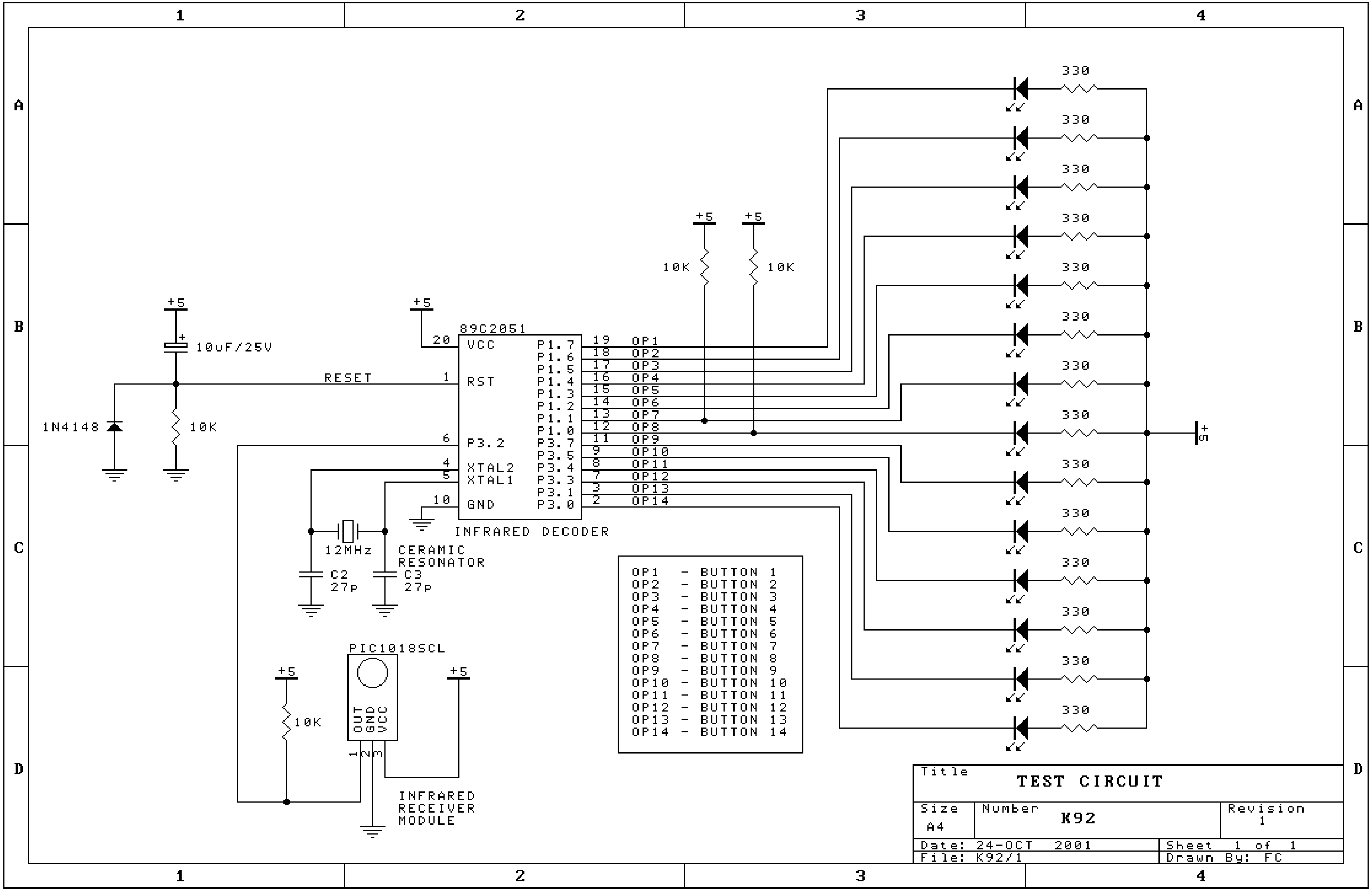
Pin	Description	Pin	Description
1	RESET, active high	20	VCC (+5V)
2	Output 14, BUTTON 14	19	Output 1, BUTTON 1
3	Output 13, BUTTON 13	18	Output 2, BUTTON 2
4	Ceramic resonator	17	Output 3, BUTTON 3
5	Ceramic resonator	16	Output 4, BUTTON 4
6	Data input (from IR receiver module)	15	Output 5, BUTTON 5
7	Output 12, BUTTON 12	14	Output 6, BUTTON 6
8	Output 11, BUTTON 11	13	Output 7, BUTTON 7
8	Output 10, BUTTON 10	12	Output 8, BUTTON 8
10	GND	11	Output 9, BUTTON 9

COMPONENTS	
330R resistor 1/4W	1
10K resistors 1/4W	4
5mm LED	1
1N4148 diode	1
10uF/25V mini ecap	1
12MHz ceramic res.	1
AT89C2051 IC	1
IR Receiver module	1
27pF ceramic caps	2
IR Remote Control	1

See our website at **http://kitsrus.com**

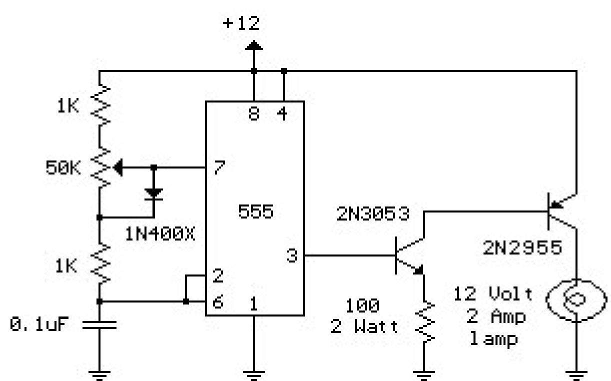
Email us at **peter@kitsrus.com** if you have any questions. Yes, we will supply any extra components you wish. Just email us. The code inside the decoder IC is locked and is not available.

K92. IR Remote Control & Decoder IC

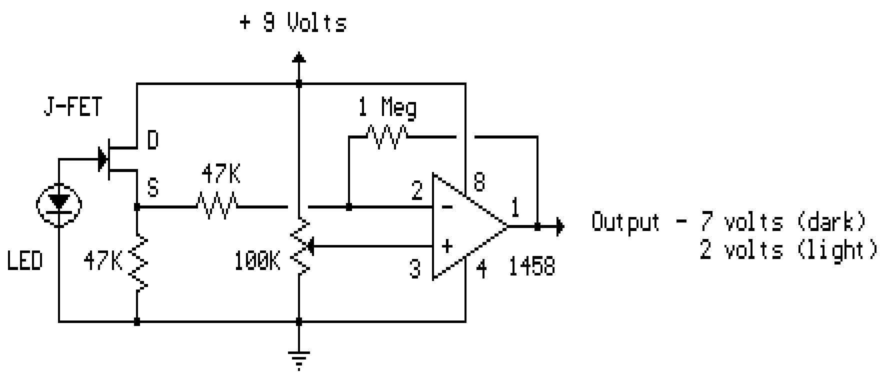


12 Volt Lamp Dimmer

Here is a 12 volt / 2 amp lamp dimmer that can be used to dim a standard 25 watt automobile brake or backup bulb by controlling the duty cycle of a astable 555 timer oscillator. When the wiper of the potentiometer is at the uppermost position, the capacitor will charge quickly through both 1K resistors and the diode, producing a short positive interval and long negative interval that dims the lamp to near darkness. When the potentiometer wiper is at the lowermost position, the capacitor will charge through both 1K resistors and the 50K potentiometer and discharge through the lower 1K resistor, producing a long positive interval and short negative interval which brightens the lamp to near full intensity. The duty cycle of the 200 Hz square wave can be varied from approximately 5% to 95%. The two circuits below illustrate connecting the lamp to either the positive or negative side of the supply.



LED Photo Sensor.



Here's a circuit that takes advantage of the photo-voltaic voltage of an ordinary LED. The LED voltage is buffered by a junction FET transistor and then applied to the inverting input of an op-amp with a gain of about 20. This produces a change of about 5 volts at the output from darkness to bright light. The 100K potentiometer can be set so that the output is around 7 volts in darkness and falls to about 2 volts in bright light.

LED-BASED MESSAGE DISPLAY

S.C. DWIVEDI

This LED-based message display is built around readily availble, low-cost components. It is easy to fabricate and makes use of 3mm red LEDs. A total of 172 LEDs have been arranged to display the message “HAPPY NEW YEAR 2004.”

The arrangement of LED1 through LED11 is used to display ‘H’ as shown in Fig. 1. The anodes of LED1 through LED11 are connected to point A and the cathodes of these LEDs are connected to point B. Similarly, letter ‘A’ is built using LED12 through LED21. All the anodes of LED12 through LED21 are connected to point A, while the cathodes of these LEDs are connected to resistor R8 (not shown in the circuit diagram). Other letters/words can also be easily arranged to make the required sentence.

The power supply for the message display circuit (Fig. 2) comprises a 0-9V, 2A step-down transformer (X1), bridge rectifier comprising diodes D1 through D4, and a filter capacitor (C1). IC 7806 (IC1)

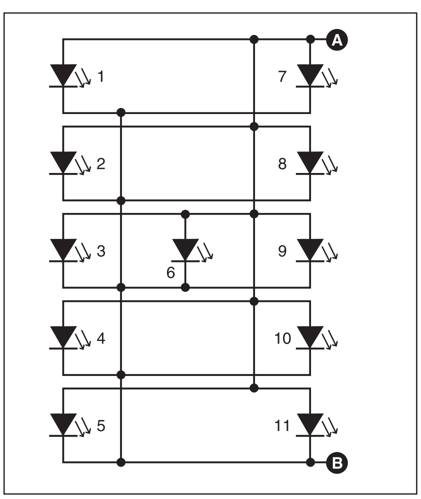


Fig. 1: LED arrangement for word ‘H’

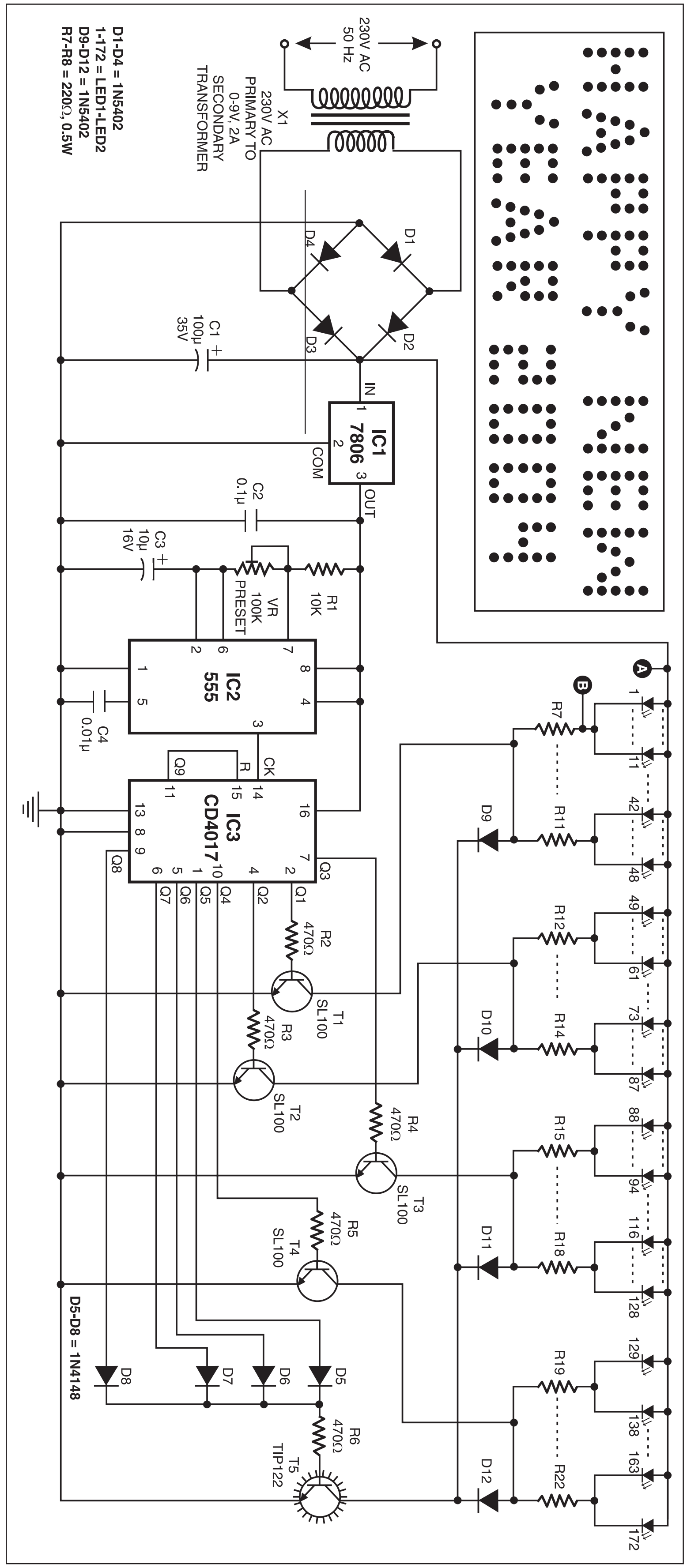


Fig. 2: Circuit diagram of LED-based message display

provides regulated 6V DC to the display circuit comprising timer 555 (IC2) and decade counter CD4017 (IC3). The astable multivibrator built around IC2 produces 1Hz clock at its output pin 3. This output is connected to clock pin (pin 14) of the decade counter.

The decade counter can count up to 10. The output of IC3 advances by one count every second (depending on the time period of astable multivibrator IC2).

When Q1 output of IC3 goes high, transistor T1 conducts and the current flows through LED1 through LED48 via resistors R7 through R11. Now the word 'HAPPY' built around LED1 through LED48 is displayed on the LED arrangement board.

Next, when Q2 output of IC3 goes high, transistor T2 conducts and the current flows through LED49 through LED87 via resistors R12 through R14. Now the word 'NEW' is displayed on the LED arrangement board.

Again, when Q3 output goes high, transistor T3 conducts and the current flows through LED88 through LED128 via resistors R15 through R18. Now the word 'YEAR' is displayed on the LED arrangement board.

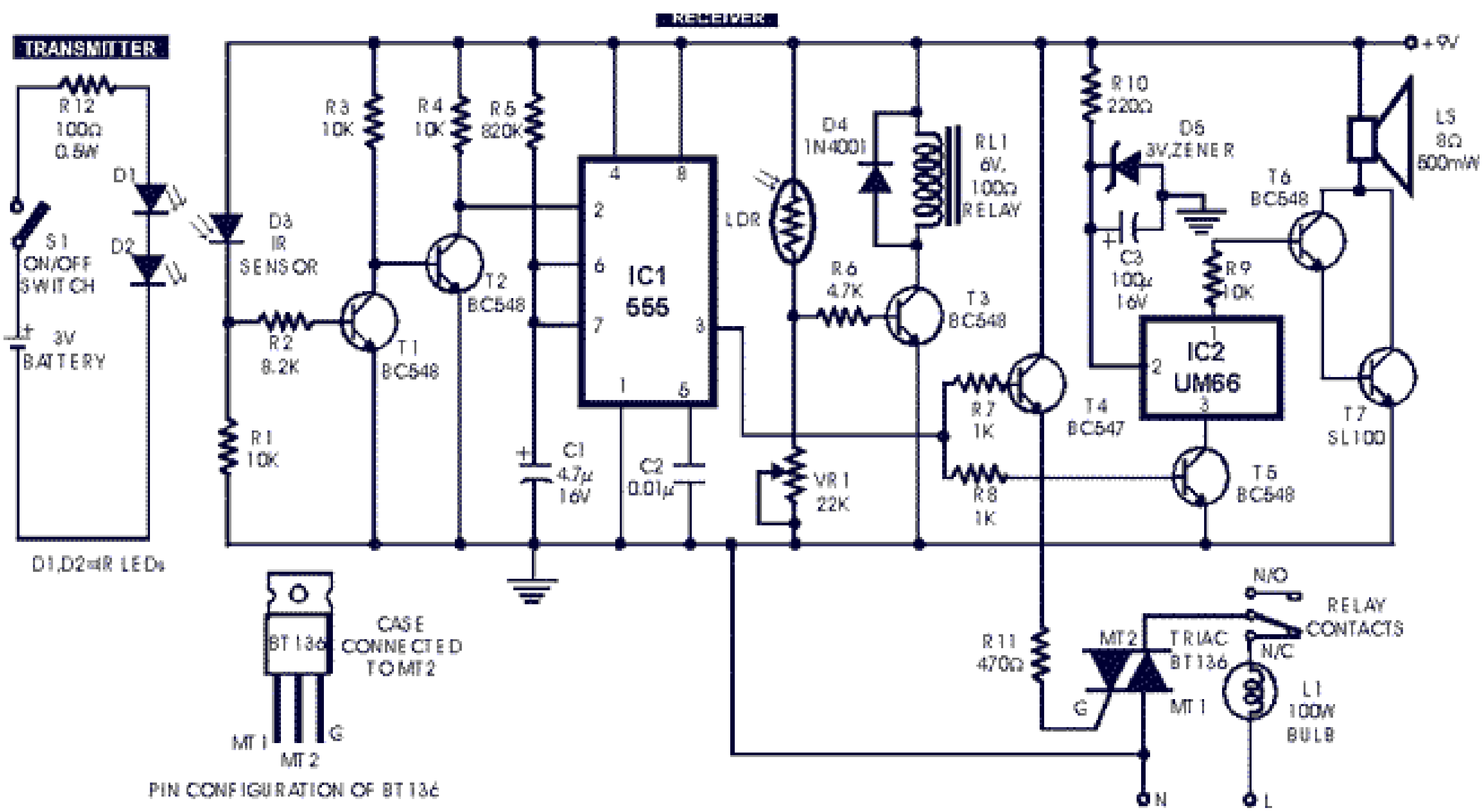
Similarly, when Q4 output goes high, transistor T4 conducts and the current flows through LED129 through LED172 via resistors R19 through R22. Now digits '2004' are displayed on the LED arrangement board.

During the entire period when Q5, Q6, Q7, or Q8 output go high, transistor T5 conducts and the current flows through all the LEDs via diodes D9 through D12 and resistors R7 through R22. Now the complete message "HAPPY NEW YEAR 2004" is displayed on the LED arrangement for four seconds.

Thus, the display board displays 'HAPPY,' 'NEW,' YEAR' and '2004' one after another for one second each. After that, the message "HAPPY NEW YEAR 2004" is displayed for 4 seconds (because Q5 through Q8 are connected to resistor R6 via diodes D5 through D8).

At the next clock input output Q9 goes high, and IC3 is reset and the display is turned off for one second. Thereafter the cycle repeats.

Low Cost Automatic Gate Light With A Musical Bell



This circuit may be used to automatically switch on a light at the entrance gate to a premises, at night, by sensing the presence of a person. In addition, it sounds a musical bell to signify the presence of the person. The lamp is switched on only for a short interval to save electricity. This circuit has two stages: a transmitting unit and a sensing unit. The transmitting unit consists of two infrared LEDs while the sensing unit consists of an IR sensor and its associated circuitry. The IR LEDs emit a beam of infrared light when switch S1 is put on. This infrared beam falls on the IR sensor D3. As a result transistor T1 gets forward biased while transistor T2 is cut-off. When any person tries to enter the gate, the IR beam falling on the IR sensor is momentarily interrupted. As a result NE555, configured as monostable flip-flop, gets a trigger pulse at its trigger input pin 2. Its output goes high for a predetermined time period. The period can be adjusted by varying the value of resistor R5 and / or capacitor C1 as T = 1.1 x R5 x C1 sec. Output pulse from IC1 forward biases transistors T4 and T5. As a result the musical bell is switched on, but the bulb is switched on only at night as explained in the succeeding paragraph. The musical bell is built around IC2 (UM66). The output from IC2 is amplified by transistors T6 and T7 to drive an 8-ohm, 500mW loudspeaker. An LDR based circuit is used to switch on the bulb at night only. The bulb is switched on when relay RL1 is de-energised. During day time the LDR

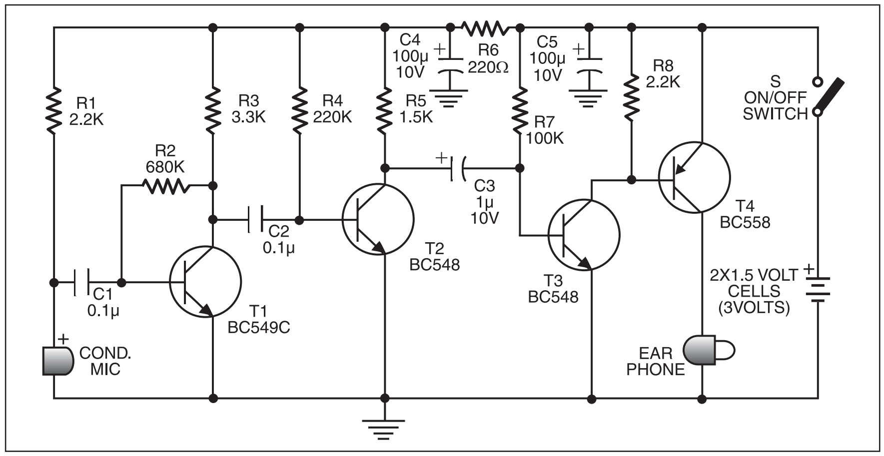
offers a very low resistance, and thus transistor T3 is forward biased to ‘on’ state and the relay RL1 is energised. In energised state of relay RL1, the main supply circuit to the bulb is incomplete. During night time the ‘dark’ resistance of LDR is very high and the relay is de-energised. As a result mains supply is connected to triac BT136 via relay contacts. When the IR beam is interrupted at night the output from IC NE555 forward biases transistors T4 and T5 as mentioned earlier. While conduction of transistor T5 sounds the musical bell, the conduction of transistor T4 causes firing of the triac. When the triac fires the mains supply to the bulb gets completed via the N/C contacts of relay RL1, and the bulb lights up. One can substitute any type of melody generator for IC UM66. The sensitivity of LDR circuit can be adjusted by varying potentiometer VR1.

LOW-COST HEARING AID

PRADEEP G.

Commercially available hearing aids are quite costly. Here is an inexpensive hearing aid circuit that uses just four transistors and a few passive components.

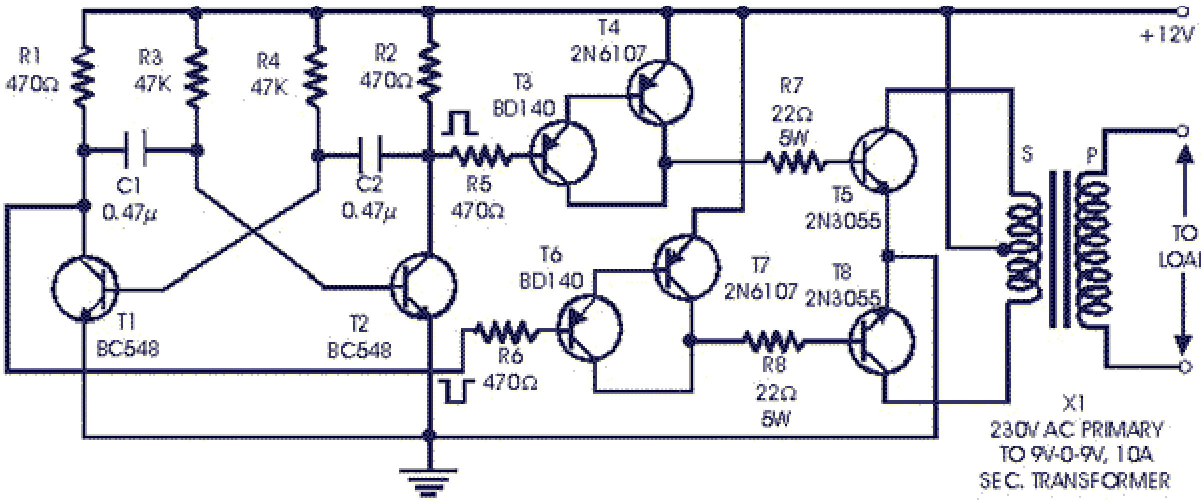
On moving power switch S to 'on' position, the condenser microphone detects the sound signal, which is amplified by transistors T1 and T2. Now the amplified signal passes through coupling capacitor C3 to the base of transistor T3. The signal is further amplified by pnp transistor T4 to drive a low-impedance earphone. Capacitors C4 and C5 are the power supply decoupling capacitors.



The circuit can be easily assembled on a small, general-purpose PCB or a Vero board. It operates off a 3V DC supply. For this, you may use two small 1.5V cells. Keep switch S to 'off' state when the circuit is not in use. To increase the sensitivity of the condenser microphone, house it inside a small tube.

This circuit costs around Rs 65.

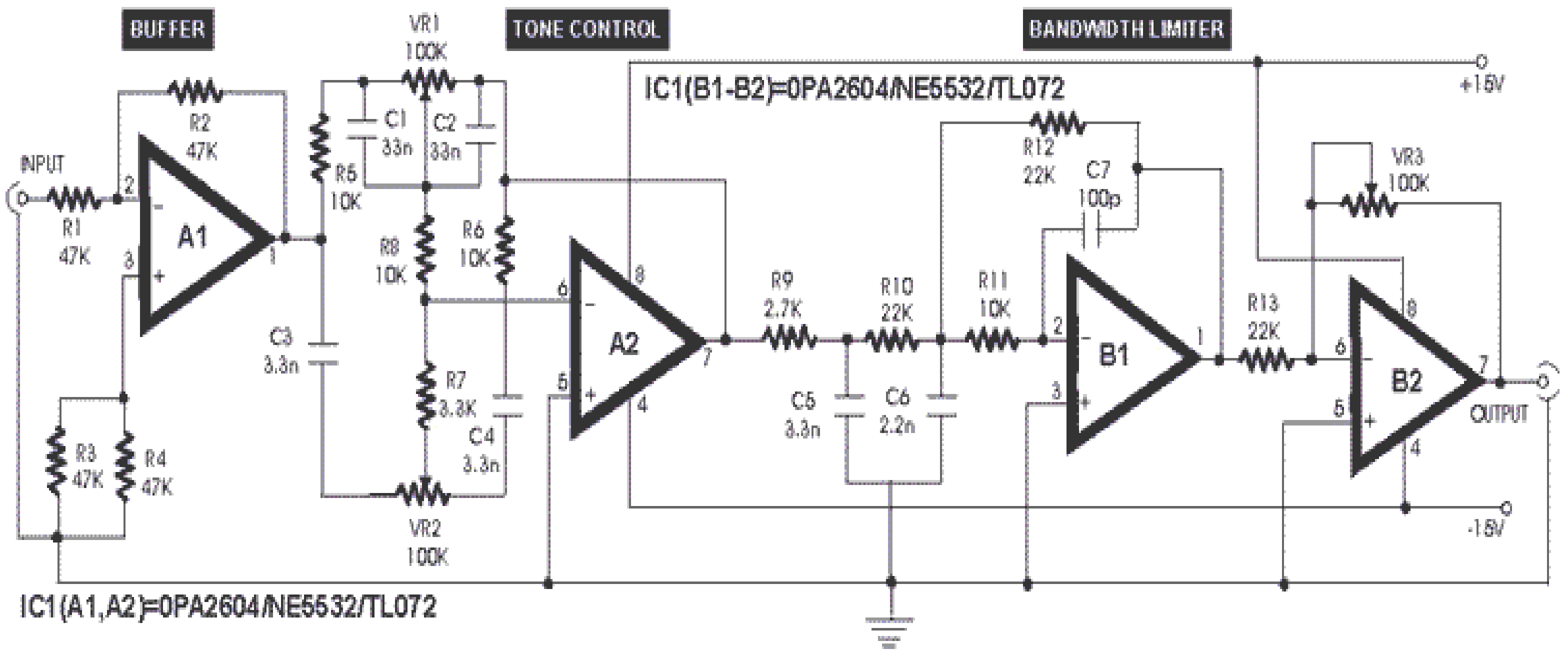
Low-Cost Transistorised Inverter



This is an inexpensive fully transistorised inverter capable of driving medium loads of the order of 40 to 60 watts using battery of 12V, 15 Ah or higher capacity. Transistors T1 and T2 (BC548) form a 50Hz multivibrator. For obtaining correct frequency, the values of resistors R3 and R4 may have to be changed after testing. The complementary outputs from collectors of transistors T1 and T2 are given to PNP darlington driver stages formed by transistor pairs T3-T4 and T6-T7 (utilising transistors BD140 and 2N6107). The outputs from the drivers are fed to transistors T5 and T8 (2N3055) connected for push-pull operation.

Somewhat higher wattage can be achieved by increasing the drive to 2N3055 transistors (by lowering the value of resistors R7 and R8 while increasing their wattage). Suitable heatsinks may be used for the output stage transistors. Transformer X1 is a 230V primary to 9V-0-9V, 10A secondary used in reverse.

A LOW DISTORTION AUDIO PREAMPLIFIER



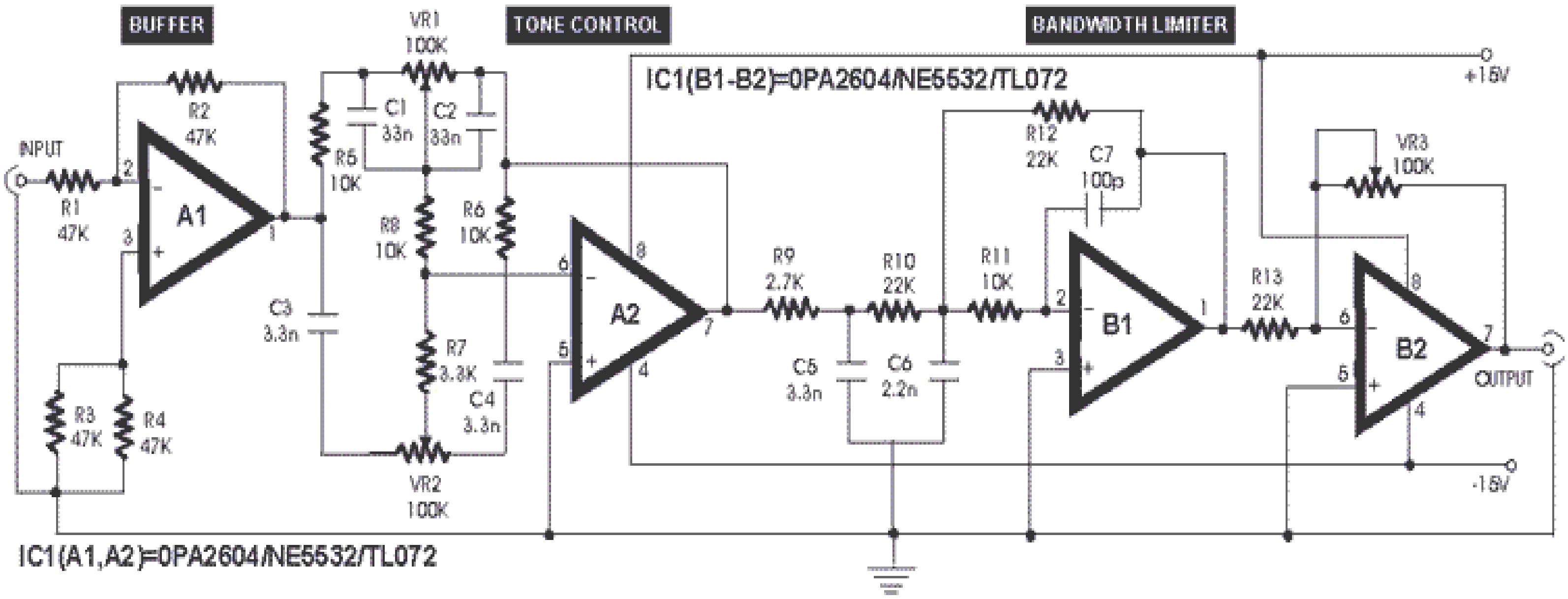
In an audio amplifier the quality of sound depends upon a number of factors, e.g. quality of active and passive components, circuit configuration, and layout. To an extent, the selection of components depends on the constructor's budget. The discrete active components like transistors have been increasingly replaced by linear ICs, making the task of designer easier. With the passage of time, the general-purpose op-amps like LM741, which were being used in audio/hi-fi circuits, have become The preamplifier circuit presented here is based on a dual precision op-amp for the construction of a low distortion, high quality audio preamplifier.

A dual op-amp OPA2604 from Burr-Brown is used for all the stages. The FET input stage op-amp was chosen in this context it is worth wile to mention another popular bi-polar architecture op-amp, the NE5534A. It has, no doubt, an exceptionally low noise figure of 4nV/ÖHz but rest of the specifications compared to OPA2604 are virtually absent in this IC. Also This IC is also capable of operating at higher voltage rails of ± 24V (max.). Also its input bias current (100 pA) is many orders lower than its bipolar counterpart's. This ensures a multifold reduction in noise.

A channel separation of 142 dB exists between In the circuit, buffer is essential for the proper working of the subsequent blocks. A nominal input impedance of 47k is offered by this stage which prevents overloading of the preamplifier. The tone control is a baxandall type filter circuit. The bandwidth limiter is basically a low-pass filter with an upper cut-off ceiling at the end of the useful audio spectrum. The gain at 10 kHz is approximately 17 dB. The design is essentially 3-pole type and the upper frequency is set at 25 kHz. This Setting the unit is fairly simple. Check the power leads feeding the IC for symmetrical voltages. High quality audio output from the line output socket is to be fed as the input signal to this preamplifier. Output of the preamplifier is fed to the power a The whole circuit

consumes about 10 mA when the above-mentioned ICs are used. Power supply requirements are not critical as the circuit works on 7.5V to 15V DC.

A Low Distortion Audio Preamplifier



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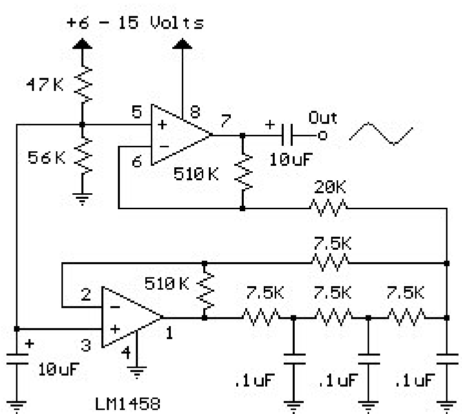
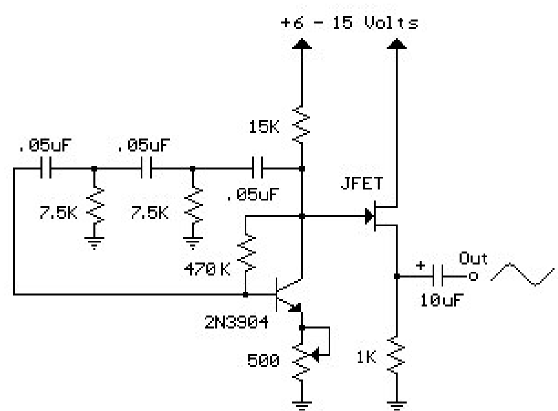
Low Frequency Sinewave Generators

The two circuits below illustrate generating low frequency sinewaves by shifting the phase of the signal through an RC network so that oscillation occurs where the total phase shift is 360 degrees. The transistor circuit on the right produces a reasonable sinewave at the collector of the 3904 which is buffered by the JFET to yield a low impedance output. The circuit gain is critical for low distortion and you may need to adjust the 500 ohm resistor to achieve a stable waveform with minimum distortion. The transistor circuit is not recommended for practical applications due to the critical adjustments needed.

The op-amp based phase shift oscillator is much more stable than the single transistor version since the gain can be set higher than needed to sustain oscillation and the output is taken from the RC network which filters out most of the harmonic distortion. The sinewave output from the RC network is buffered and the amplitude restored by the second (top) op-amp which has gain of around 28dB. Frequency is around 600 Hz for RC values shown (7.5K and 0.1uF) and can be reduced by proportionally increasing the network resistors (7.5K). The 7.5K value at pin 2 of the op-amp controls the oscillator circuit gain and is selected so that the output at pin 1 is slightly clipped at the positive and negative peaks. The sinewave output at pin 7 is about 5 volts p-p using a 12 volt supply and appears very clean on a scope since the RC network filters out most all distortion occurring at pin 1.

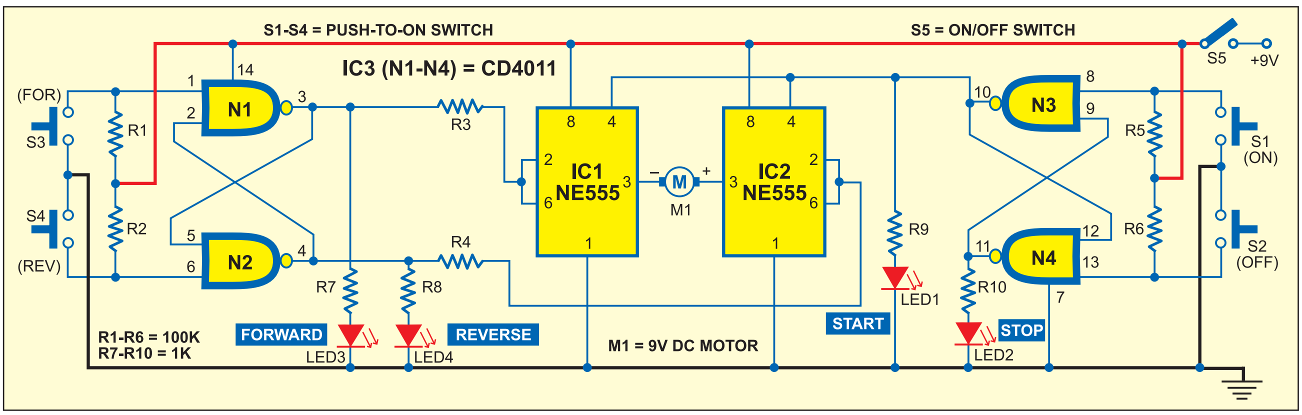




MICROMOTOR CONTROLLER

■ V. DAVID

Using this circuit, you can control the rotation of a DC micromotor simply by pressing two push-to-on switches momentarily.



The circuit is built around two NE555 ICs (IC1 and IC2) and a quad-NAND IC CD4011 (comprising NAND gates N1 through N4). The NE555 ICs (IC1 and IC2) are configured as inverting buffers. IC CD4011 (IC3) NAND gates are configured as bistable flip-flop. The DC motor to be controlled is connected between the outputs (pin 3) of IC1 and IC2.

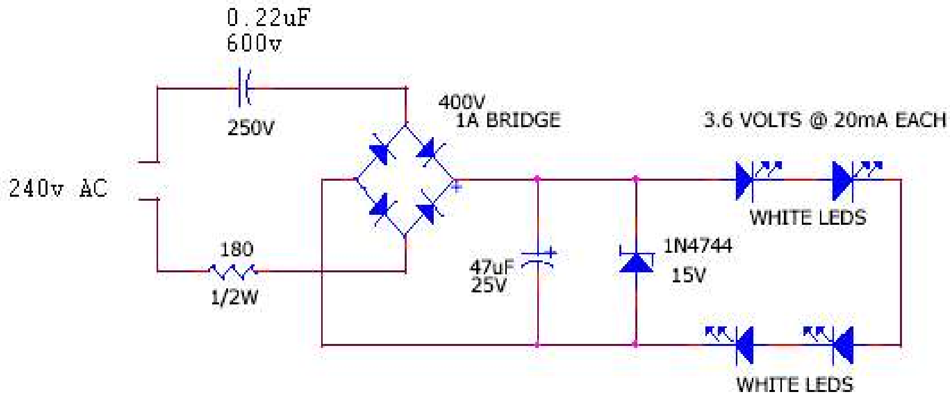
Closing switch S5 provides power to the circuit. Now, when you press switch S1 momentarily, pin 10 of IC3 goes high, while its pin 11 goes low. Since pin 10 of IC3 is connected to reset pin 4 of IC1 and IC2, the high output at pin 10 of IC3 will enable IC1 and IC2 simultaneously. When switch S2 is pressed, pin 10 of IC3 goes low, while its pin 11 goes high. The low logic at pin 10 disables both IC1 and IC2.

Switches S3 and S4 are used for forward and reverse motion of the motor in conjunction with switch S1. If you press switch S3 after pressing switch S1, pin 3 of IC3 goes high, while its pin 4 goes low. The motor now starts rotating in the forward direction. However, if you press switch S4 after pressing switch S1, the motor will rotate in reverse direction.

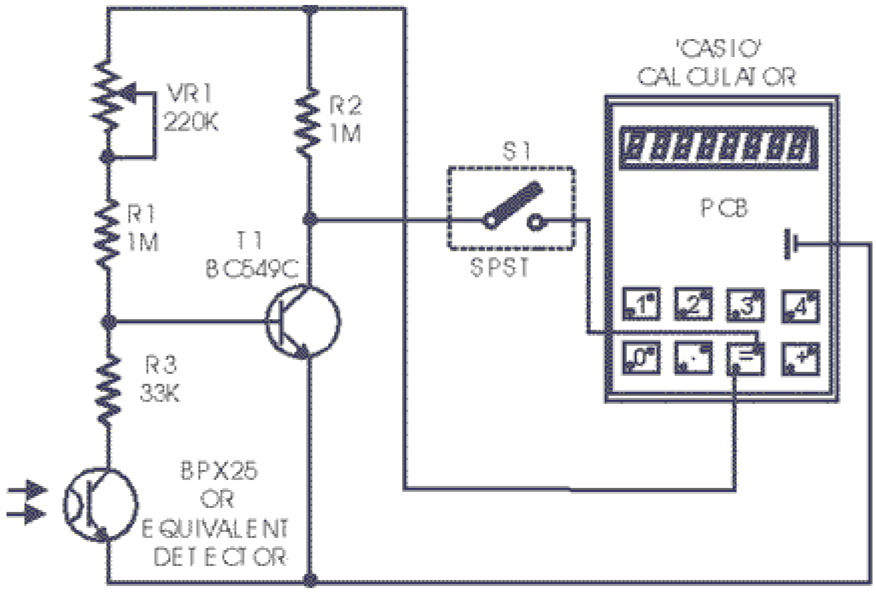
Note. The complete kit of this circuit can be obtained from Kits'n'Spares, 303, Dohil Chambers, 46, Nehru Place, New Delhi 110019; Phone: 011-26430523, 26449577; Website: www.kitsnspares.com; E-mail: kits@efyindia.com. ●

NIGHT LIGHT

This simple circuit on 240v AC. It uses four white light emitting diodes (LED) in conjunction with a capacitor coupled full wave rectifier circuit. The circuit draws less than one half of one watt of power and can therefore run continuously. In spite of the low power, the LEDs provide sufficient illumination for most night light applications.



Ready-to-use Object Counter



Presented here is the cheapest 8-digit programmable object or event counter. It is a fail-proof, fool-proof, power failure-proof, one evening project. A general-purpose (arithmetic) calculator has some inherent shortcomings which can, however, be used in many ways by proper programming sequences. For example, there is no squaring key in a general-purpose calculator, but it can not only square it has even the inherent capability of a single touch successive multiplication, thus giving us a choice of making a geometric progression (G.P.) or successive addition or forming an arithmetic progression (A.P.). For example, operating the keys 5,x,=,=,... you obtain the G.P. 5,25,125,625,... or by operating keys 5,x,4,=,=,=,..., you get the G.P.: 4,20, 100,500,... Next, operate keys: 5,+, 2,=,=,... to get the A.P.: 5,7,9,11,13,... The latter facility (A.P.) has been used here to count the objects by programming the calculator keys 1,+,=,=,... When you open the calculator (such as 'Casio'), you will find that the conductive silicon key pads bridge the two terminals of a key, when depressed. Locate the switch terminals for (=) key and check the polarity of the terminals with respect to the battery negative. The terminal which is found to be positive is to be connected to the junction of R2 and VR1, and the other terminal is to be connected to switch S1 as shown in the figure. The negative battery terminal is to be connected to emitters of photo-transistor and transistor T1. (There may be slight difference in the use of key terminals in different brands of calculators.) The optical sensor used here is BPX25, a very sensitive photo-transistor which has a built-in lens to focus the incident light on to the chip. Only two leads, emitter and collector, have been used. When light falls on the sensor, it conducts as if it had got forward biased. A variable resistor of 220k in series with another fixed resistor of 1 M (selected by trial) has been used at the base of transistor T1 (BC149C/BC 549C) to set the threshold level for its conduction, depending upon the intensity of light used. When light is obstructed, BPX goes to cut-off, transistor T1 conducts and the terminal of (=) key which is connected via switch S1 (assuming closed), goes low. This is equivalent to depression of the (=) key. When light again falls on the sensor, it conducts and the base of transistor T1 goes low, throwing it

to cut-off, so that its collector and hence the (=) key gets connected to the positive bus via 1 M resistor R2. A pulse is passed on and the calculator advances by 1. Current drain from the battery is less than 50 μA, which a button cell can easily provide. The counter is slow but there is no switch debouncing effect present, which makes the counter highly reliable and ideal as a slow event counter in applications such as visitor counter. Further, the circuit is auto-locked, since any resetting is possible only when BPX is in the cut-off position, i.e., in darkness. To program, cover the phototran- sistor and operate keys : 1,+,=. In case of a deadlock in programming, miniature switch S1 may be used to enable isolation of the (=) key. Set the 220k preset according to the ambient and the incident light, so that the calculator counts when light is cut-off and again allowed to fall when obstruction is removed. If it is used to count visitors in a well day-lighted environment, only a white washed wall or a white paper pasted on the opposite door panel is sufficient. For indoor applications, a specific source of light is required. Both the source of light as well as the BPX should then be mounted in opaque (preferably black) tubes and a lens be fitted in the light-source tube to focus the light on to the photo-transistor. BC149C/549C is preferred due to its large current gain of the order of 300 at 10 μA, compared to 150 that of BC548B, so that the instrument becomes more sensitive.

Radio Control Electric Switch

This switch is quite simple but has some great features and worth a try. All of the parts are readily available from most electronics stores or if you tinker with electronics a bit you may have them in your junk box as odd spares.

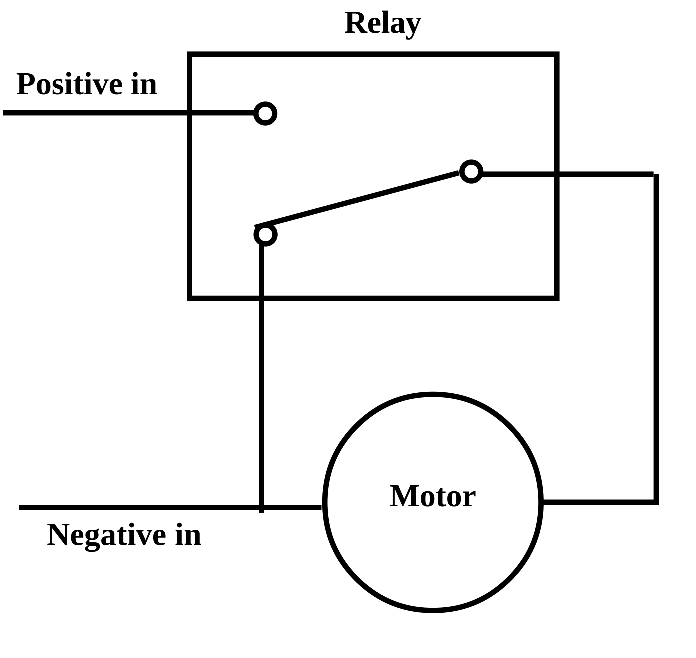
I've recorded how to make the printed circuit board as it is so easy and is a rewarding experience to complete the whole job yourself. There are no suggestions of how to mount the switch.

As you can see by the photo, I didn't put it in a case as it would just add weight and I can't see why it would need it if you can have it held by foam rubber. I cut a cavity out of some foam and wrapped a rubber band around it all.

The relay is mounted away from the circuit so the motor current has less effect and cause glitches and mounted with double foam tape. I mounted the relay away from the board to keep electrical interference to a minimum.

The circuit doesn't have to be made like this as you could have a go at building it up on a veroboard but I do find it a fair bit harder, some don't. It is a bit bigger than it's commercial counterparts but this is as small as I think most people can go with an ordinary soldering iron and tools.

A 6v relay seems to work fine even though the receiver voltage is only 4.8v. There are no pads included on the P.C board for the switching side of the relay as it depends on what sort is used. Be sure to find one that can handle the current that is put through it and do a good job of the soldering as there is a lot of vibration in a model aircraft.



A double pole relay can be wired to short out the motor when power isn't on so a folding prop can stop rotating and fold properly. *See diagram in previous column.*

Adjust the trim pot so that the relay turns on at the desired position of the radio stick. Note there is a slight delay in switching.

You can get a receiver plug by buying a servo extension lead and cutting it to the desired length.

<u>How to make P.C Board.</u>

Buy ;

Blank board copper on one side. *(Fibreglass is preferable but the older bakalite type material is ok. It fractures easier though*)
Dalo pen
Ferric chloride (*You can get it already as a solution or as powder and mix it yourself. Read the warnings about it's corrosive properties as you may end up with no sink pipes*.)
Carbon paper (*The same sort of stuff that you get in receipt books etc.*)

Draw out diagram by placing the carbon paper onto copper face and the master on top. Then fill in the tracks you've drawn onto the copper with the Dalo pen. Cut board to size & put in Ferric Chloride till excess copper is etched. You could warm up the ferric chloride to make it work a little quicker. Swish the solution around a bit to keep fresh solution up to the copper. Wash & clean up then drill holes. The holes are quite small and you may need to but that size drill at an electronics store as well. Centre punch the holes first makes it easier to drill.

This is what mine looks like in situ.

You may need to obtain a chart that shows how to orientate the transistors the right way. In the diagram there are markings for each leg as B,E,C which is base, emitter and collector. These have to be the right way round and as they vary on different transistors of the same sort you'll have to do some digging yourself or as the supplier of the parts.

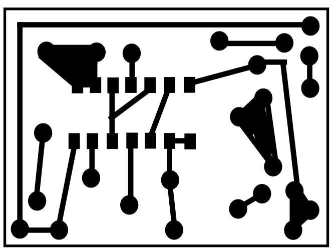
The Integrated circuit the electrolytic capacitor and the diode are the other three parts that must go the right way. The IC usually has a notch or similar at the end that corresponds with pin one marked on the diagram. The diode has a black band at one end and that also can be seen on the diagram. The capacitor usually has negative or positive marked on the case and you'll see the + marked on the board diagram.

The trim pot RV1 uses only the middle and one outside leg. Just bend the other out of the way.

To find the way to wire the receiver plug, look on your servo wires and see if there is a red, black and another colour wire as it is probably red for positive, black for negative.

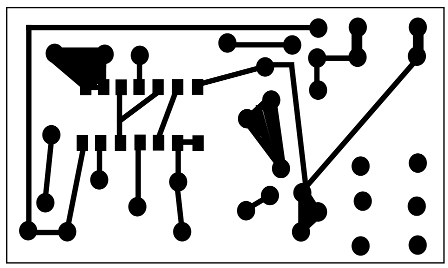
Copper Side

without relay



Full Scale

with relay



Parts List

Resistors

R1.......68k ohm 0.5 w
R2..... 10k ohm 0.5 w
R3.......10k ohm 0.5 w
R4..... 4.7k ohm 0.5 w

Capacitors

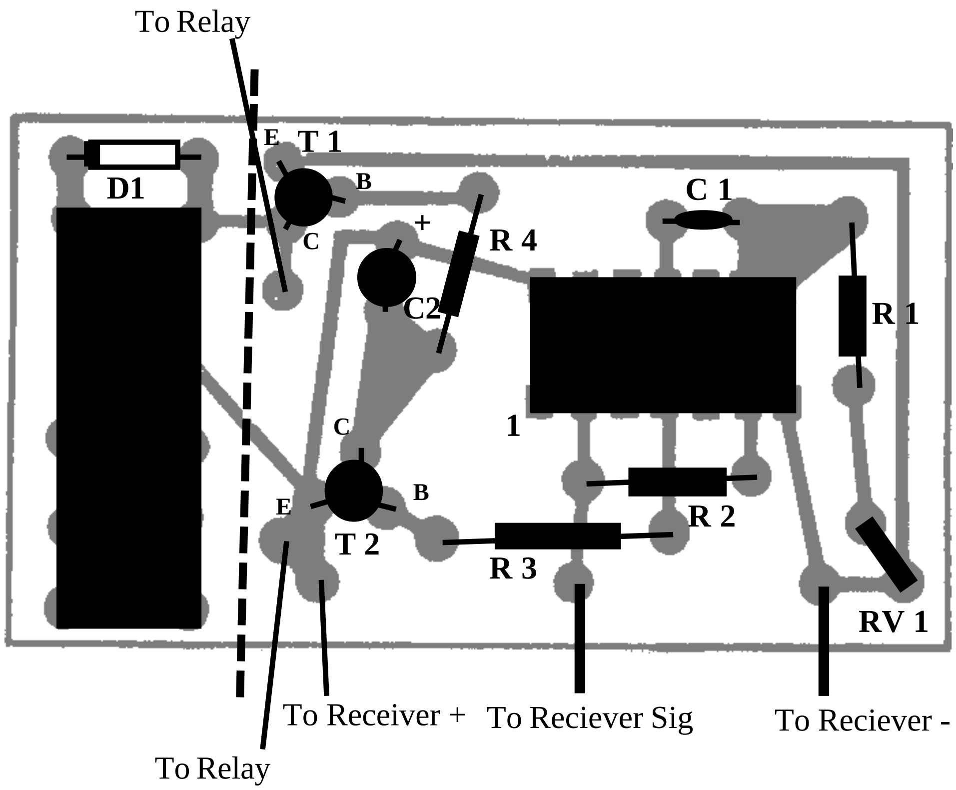
C1........022 uF Polyester
C2.......47uf electrolytic

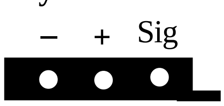
Semiconductors

D1......1N 4004
T1......Bc 549
T2......Bc 559
IC1....4011

Miscellaneous

RV 1...100K trim pot
Relay



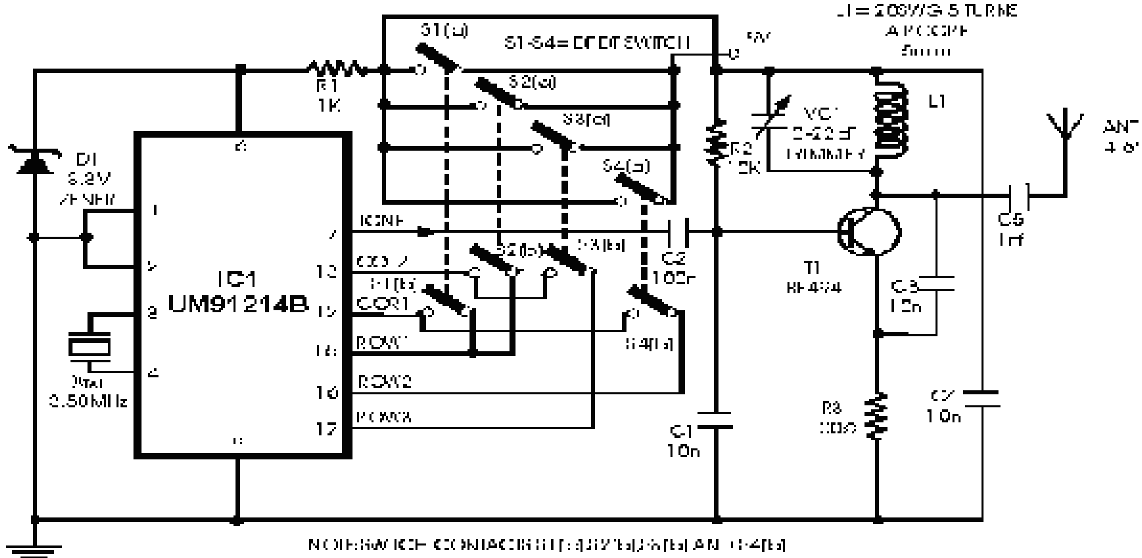


Futaba Plug

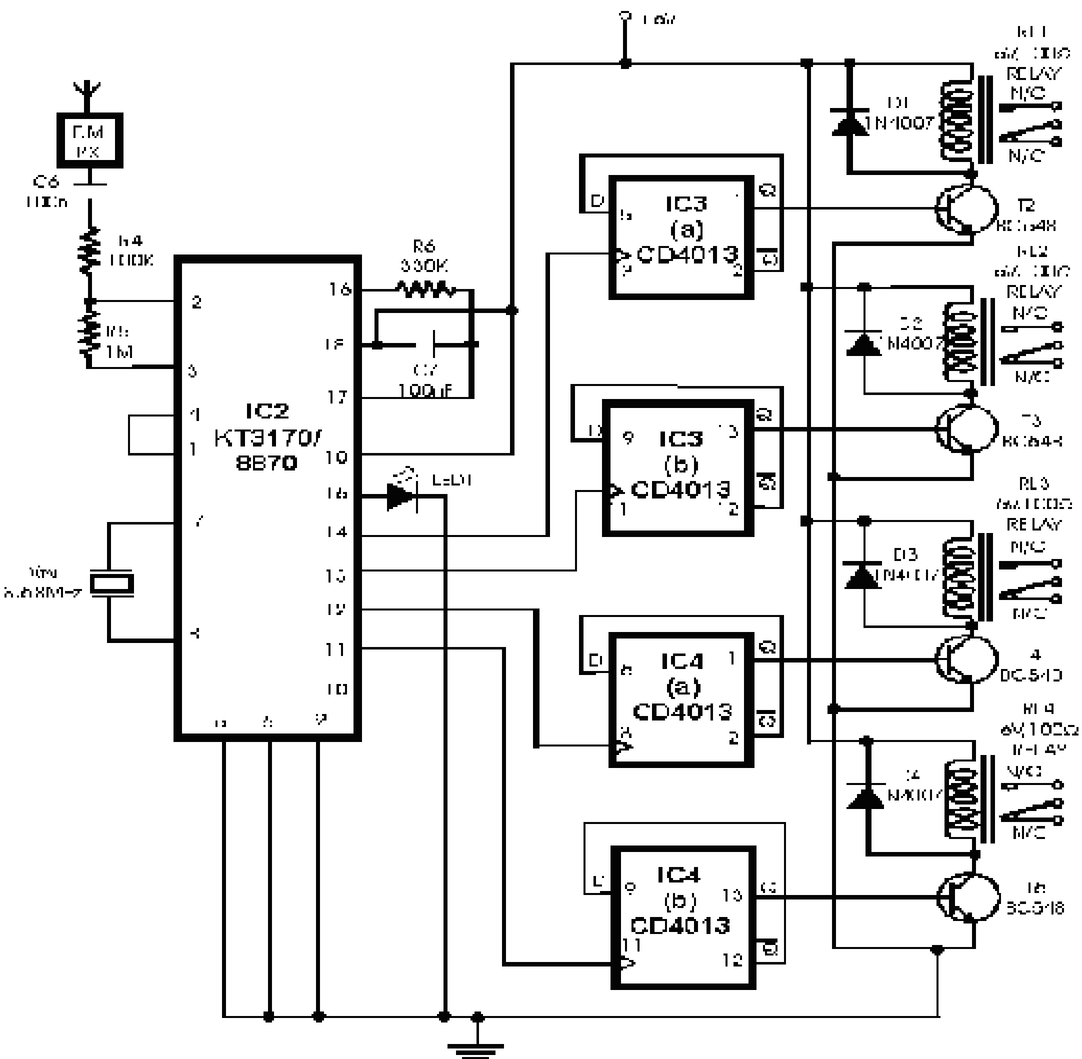
NB. If Mounting Relay Off The Board You Still Need The Diode. Mount it on the relay & be sure it's facing the right way.

Radio Remote Control using DTMF

Here is a circuit of a remote control unit which makes use of the radio frequency signals to control various electrical appliances. This remote control unit has 4 channels which can be easily extended to 12. This circuit differs from similar circuits in view of its simplicity and a totally different concept of generating the control signals. Usually remote control circuits make use of infrared light to transmit control signals. Their use is thus limited to a very confined area and line-of-sight. However, this circuit makes use of radio frequency to transmit the control signals and hence it can be used for control from almost anywhere in the house. Here we make use of DTMF (dual-tone multi frequency) signals (used in telephones to dial the digits) as the control codes. The DTMF tones are used for frequency modulation of the carrier. At the receiver unit, these frequency modulated signals are intercepted to obtain DTMF tones at the speaker terminals. This DTMF signal is connected to a DTMF-to-BCD converter whose BCD output is used to switch-on and switch-off various electrical applicances (4 in this case). The remote control transmitter consists of DTMF generator and an FM transmitter circuit. For generating the DTMF frequencies, a dedicated IC UM91214B (which is used as a dialler IC in telephone instruments) is used here. This IC requires 3 volts for its operation. This is provided by a simple zener diode voltage regulator which converts 9 volts into 3 volts for use by this IC. For its time base, it requires a quartz crystal of 3.58 MHz which is easily available from electronic component shops. Pins 1 and 2 are used as chip select and DTMF mode select pins respectively. When the row and column pins (12 and 15) are shorted to each other, DTMF tones corresponding to digit 1 are output from its pin 7. Similarly, pins 13, 16 and 17 are additionally required to dial digits 2, 4 and 8. Rest of the pins of this IC may be left as they are. The output of IC1 is given to the input of this transmitter circuit which effectively frequency modulates the carrier and transmits it in the air. The carrier frequency is determined by coil L1 and trimmer capacitor VC1 (which may be adjusted for around 100MHz operation). An antenna of 10 to 15 cms (4 to 6 inches) length will be sufficient to provide adequate range. The antenna is also necessary because the transmitter unit has to be housed in a metallic cabinet to protect the frequency drift caused due to stray EM fields. Four key switches (DPST push-to-on spring loaded) are required to transmit the desired DTMF tones. The switches when pressed generate the specific tone pairs as well as provide power to the transmitter circuit simultaneously. This way when the transmitter unit is not in use it consumes no power at all and the battery lasts much longer. The receiver unit consists of an FM receiver (these days simple and inexpensive FM kits are readily available in the market which work exceptionally well), a DTMF-to-BCD converter and a flip-flop toggling latch section. The frequency modulated DTMF signals are received by the FM receiver and the output (DTMF tones) are fed to the dedicated IC KT3170 which is a DTMF-to-BCD converter. This IC when fed with the DTMF tones gives corresponding BCD output; for example, when digit 1 is pressed, the output is 0001 and when digit 4 is pressed the output is 0100. This IC also requires a 3.58MHz crystal for its operation. The tone input is connected to its pin 2 and the BCD outputs are taken from pins 11 to 14 respectively. These outputs are fed to 4 individual 'D' flip-flop latches which have been converted into toggle flip-flops built around two CD4013B ICs. Whenever a digit is pressed, the receiver decodes it and gives a clock pulse which is used to toggle the corresponding flip-flop to the alternate state. The flip-flop output is used to drive a relay which in turn can latch or unlatch any electrical appliance. We can upgrade the circuit to control as many as 12 channels since IC UM91214B can generates 12 DTMF tones. For this purpose some modification has to be done in receiver unit and also in between IC2 and toggle flip-flop section in the receiver. A 4-to-16 lines demultiplexer (IC 74154) has to be used and the number of toggle flip-flops have also to be increased to 12 from the existing



NOTE: SWITCH CONTACTS S1(b), S2(b), S3(b) AND S4(b) CORRESPOND TO DIGITS 1, 2, 4 AND 8 RESPECTIVELY OF TELEPHONE PAD SWITCHES



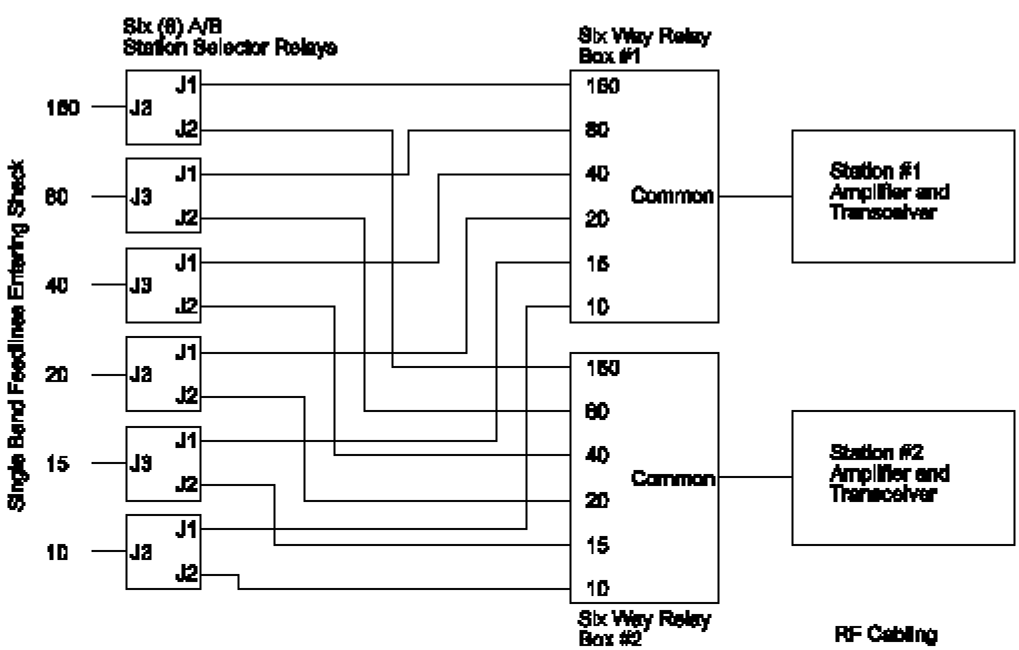
Subject: Stacking Six A/B Station Selector Relays

Background:

The A/BSS relay was designed for the two-rig contest station where any antenna not in use by the first station should be available to the second station. Initial implementations of this concept used Band Decoders and Six Way Relay Boxes on both stations, with the switching of the antennas themselves between the two stations being done manually.

Typically, a bank of six SP2T coax switches, commonly available from MFJ and Daiwa, would be used for this purpose. Although all the other switching could be accomplished automatically by the Band Decoders and Six Ways, the operator had to manually adjust the proper SP2T switch before transmitting (or at least glance at the switch to verify that it was in the correct position).

The A/BSS relays replace the manual switches, allowing the operators to freely roam the various bands with all antenna switching being automatic. The recommended configuration looks like this:



Possibility to Eliminate the Six Ways:

You can see from the above diagram that the array of two Six Ways and six A/BSS relays form a switching system which is (looking from the antenna side) "Six In/Two Out." This same functionality can be obtained by eliminating the Six Ways, and bussing the A/BSS A ("J1") Outputs together and bussing the A/BSS B ("J2") outputs together.

This is accomplished using standard coaxial adapters (male-male, Tee, and elbow). Be sure to use good quality fittings. We tried some inexpensive imported connectors with disastrous results due to many of them being so "loose" that no rf connection was made.

Build the stack in the following manner. Install Tees on Outputs A and B on Boxes 1 through 5. Install elbows on Outputs A and B on Box 6. Join Boxes 1 and 2 with male-male adapters. Repeat for all the boxes until you have a stack of six A/BSS relays joined by the adapter fittings making busses for Outputs A and B. These outputs now appear on the unoccupied end of the Tee fittings on Box 1.

As far as mechanical mounting is concerned, you are left to you own devices. Although the stack is relatively rigid inherently, we recommend that stress relief on the fittings be considered in any mounting arrangement. One way that comes to mind is to clamp the busses to the underside of a table or other surface, allowing the A/BSS relays and their attached antenna leads to hang in the downward direction.

Performance of the "Two by Six Stack"

VSWR was measured at 14 and 28 MHz with a 50 ohm dummy load attached to the input (antenna) connector of each of the six boxes. The appropriate relay was energized and rf applied to Port B, with results as follows:

	Box 1	Box 2	Box 3	Box 4	Box 5	Box 6
14 MHz	1.15	1.09	1.05	1.02	1.0	1.07
28 MHz	1.65	1.45	1.2	1.15	1.15	1.2

The total capacitance looking into an open Port A or Port B is about 85 pF. The calculated VSWR with 85 pF across 50 ohms is 1.67 at 10 meters, which

correlates nicely with the measured data. This capacitance can be eliminated by installing a 0.38 µH compensating inductor across the 10 meter output. If flat VSWR is not all that important to you, merely use Box 1 for 160, Box 2 for 80, etc., ending up with Box 6 on 10 meters.

Port to port isolation tests were run at 28 MHz and 14 MHz. 100 watts was inserted at Port A or B, and readings taken at the other Port, for each of the six possible cases per band. Due to the vagaries of stray capacitance, results are not precisely repeatable. However, the Port A to Port B isolation is typically greater than 85 dB at 28 MHz and 95 dB at 14 MHz. This is far in excess of the typical 60 dB required to prevent receiver front end damage when running 1500 watts through one of the ports.

Comments:

1. Using this approach, you can save the cost of two Six Way Relay Boxes, and twelve coax jumper cables, each with a PL-259 connector. However, if your junk box is sparse, you will have to acquire the necessary 10 Tees, 10 male-males, and 2 elbows. Using prices from the Newark Electronics catalog, these adapters would cost in excess of $250! A little shopping reveals The R.F. Connection (http://www.therfc.com) where you can pick up all 22 connectors for $121.50. The point is that the approximately $225 saving realized by eliminating the Six Ways and attendant cables can be very quickly eroded in adapter costs.
2. VSWR characteristics are certainly acceptable on the stack. However, better performance can be expected from the full implementation using the additional Six Ways, in that 50 ohm impedance paths are maintained throughout.
3. Port to port isolation is also very good at 85 dB or greater. However, the full implementation will display significantly more isolation due to the additional open relay contacts in the circuit.
4. Reliability of the "switching system" would be expected to be greater with the stack due to fewer components. (The very same relays are used in both the Six Way and the A/BSS.) However, "on-line repairability" of the stack is virtually non-existent, due to the way the boxes are electrically and mechanically coupled. On the other hand, the full implementation with two Six Ways allows access to either a failed Six Way or a failed A/BSS while the other station continues on the air. For example, if the 40 meter A/BSS fails, it can be easily removed from the switching system by disconnecting the coax jumpers. The two stations continue to operate normally on all bands EXCEPT 40 meters. If Station

1's Six Way fails, Station 2 continues to operate normally while the repair is being made.

Please note that the reliability of our rf switching products when installed properly and operated within ratings has proved to be exceptionally high.

ADD-ON STEREO CHANNEL SELECTOR

PRABHASH K.P.

The add-on circuit presented here is useful for stereo systems. This circuit has provision for connecting stereo outputs from four different sources/channels as inputs and only one of them is selected/ connected to the output at any one time.

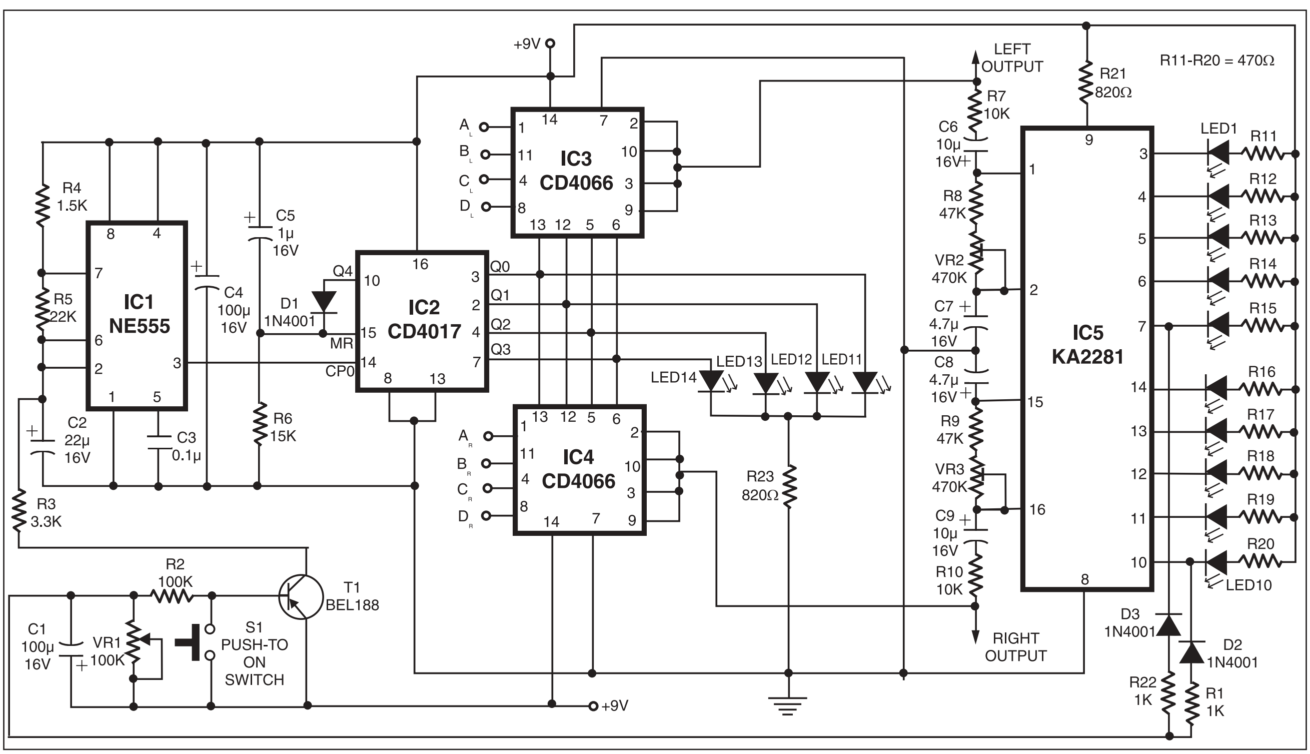
When power supply is turned 'on', channel A (A2 and A1) is selected. If no audio is present in channel A, the circuit waits for some time and then selects the next channel (channel B), This search operation continues until it detects audio signal in one of the channels. The inter-channel wait or delay time can be adjusted with the help of preset VR1. If still longer time is needed, one may replace capacitor C1 with a capacitor of higher value.

Suppose channel A is connected to a tape recorder and channel B is connected to a radio receiver. If initially channel A is selected, the audio from the tape recorder will be present at the output. After the tape is played completely, or if there is sufficient pause between consecutive recordings, the circuit automatically switches over to the output from the radio receiver. To manually skip over from one (selected) active channel, simply push the skip switch (S1) momentarily once or more, until the desired channel inputs gets selected. The selected channel (A, B, C, or D) is indicated by the glowing of corresponding LED (LED11, LED12, LED13, or LED14 respectively).

IC CD4066 contains four analogue switches. These switches are connected to four separate channels. For stereo operation, two similar CD4066 ICs are used as shown in the circuit. These analogue switches are controlled by IC CD4017 outputs. CD4017 is a 10-bit ring counter IC. Since only one of its outputs is high at any instant, only one switch will be closed at a time. IC CD4017 is configured as a 4-bit ring counter by connecting the fifth output Q4 (pin 10) to the reset pin. Capacitor C5 in conjunction with resistor R6 forms a power-on-reset circuit for IC2, so that on initial switching 'on' of the power supply, output Q0 (pin 3) is always 'high'. The clock signal to CD4017 is provided by IC1 (NE555) which acts as an astable multivibrator when transistor T1 is in cut-off state.

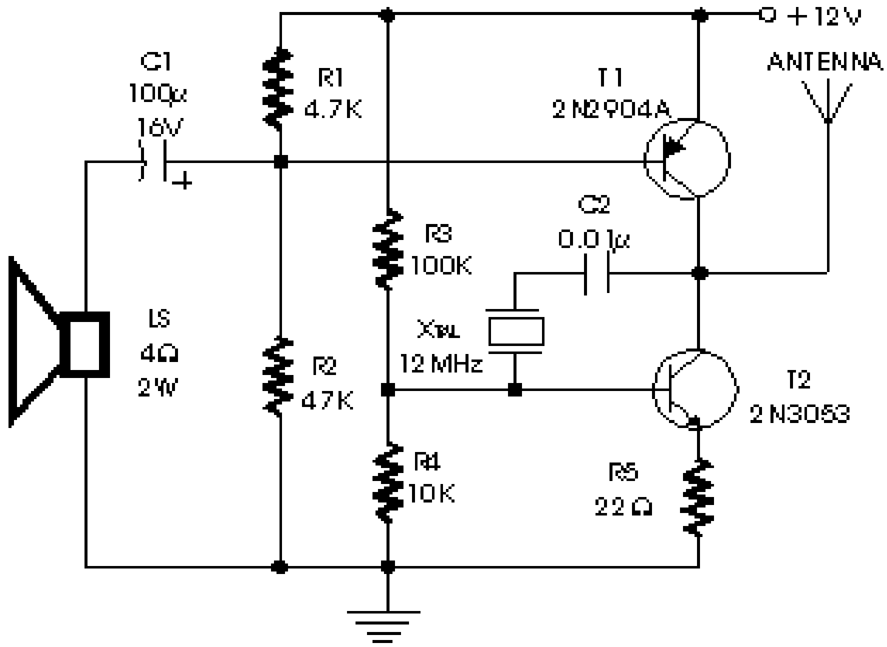
IC5 (KA2281) is used here for not only indicating the audio levels of the selected stereo channel, but also for forward biasing transistor T1. As soon as a specific threshold audio level is detected in a selected channel, pin 7 and/ or pin 10 of IC5 goes 'low'. This low level is coupled to the base of transistor T1, through diode-resistor combination of D2-R1/D3-R22. As a result, transistor T1 conducts and causes output of IC1 to remain 'low' (disabled) as long as the selected channel output exceeds the preset audio threshold level.

Presets VR2 and VR3 have been included for adjustment of individual audio threshold levels of left stereo channels, as desired. Once the multivibrator action of IC1 is disabled, output of IC2 does not change further. Hence, search-



ing through the channels continues until it receives an audio signal exceeding the preset threshold value. The skip switch S1 is used to skip a channel even if audio is present in the selected channel. The number of channels can be easily extended up to ten, by using additional 4066 ICs.

Short Wave AM Transmitter



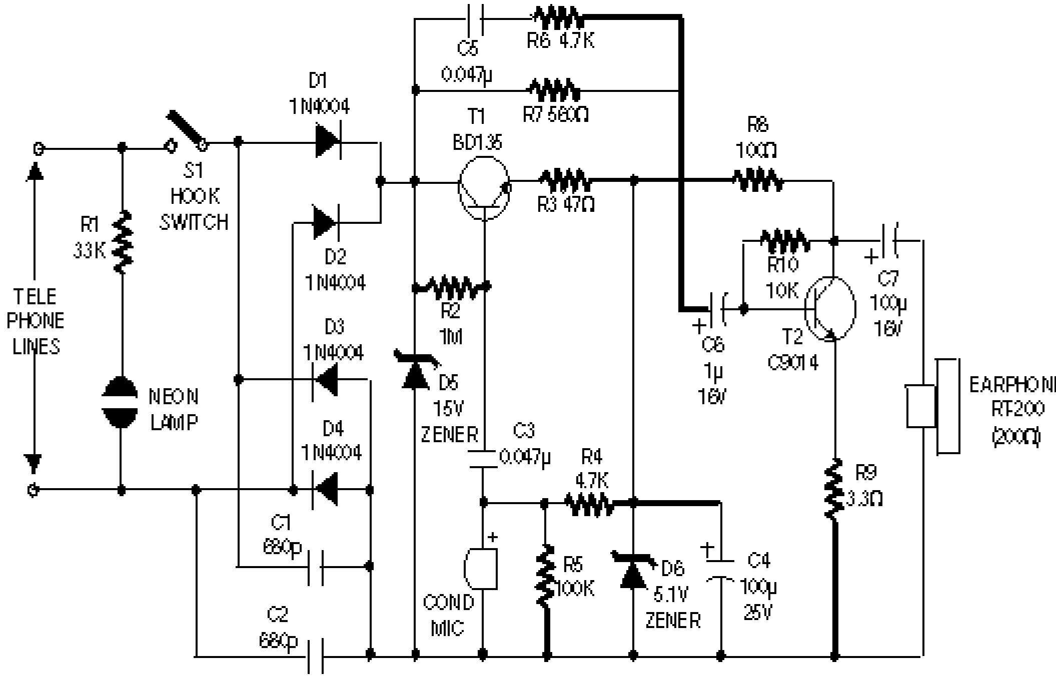
The main feature of this trans- mitter is that it is free from the LC (inductor, capacitor) tuned circuit and operates on a fixed frequency of 12 MHz which is extremely stable. An LC based tuned circuit is inherently unstable due to drift of resonant frequency on account of temperature and humidity variations. The circuit is very simple and uses only a few components. The figure shows the complete circuit diagram of the transmitter. Resistors R1 and R2 are used for DC biasing of transistor T1. The capacitor C1 provides coupling between the speaker and the base of transistor T1. Similarly, resistors R3, R4 and R5 provide DC bias to transistor T2. Resistor R5 also provides negative feedback which results in higher stability. The oscillator section is a combination of transistor T2, crystal Xtal, capacitor C2 and resistors R3, R4 and R5. The crystal is excited by a portion of energy from the collector of transistor T2 through the feedback capacitor C2. Thus the oscillator circuit generates the carrier frequency at its fundamental frequency of 12 MHz. Any crystal having the frequency in short wave range can be substituted in this circuit, although the operation was tested with a 12MHz crystal. Transistor T1 serves three functions:

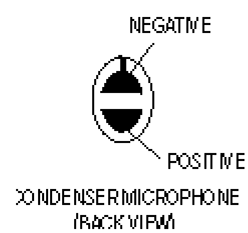
* It provides the DC path for extending +Vcc supply to transistor T2.
* It amplifies the audio signals obtained from speaker.
* It injects the audio signal into the high frequency carrier signal for modulation.

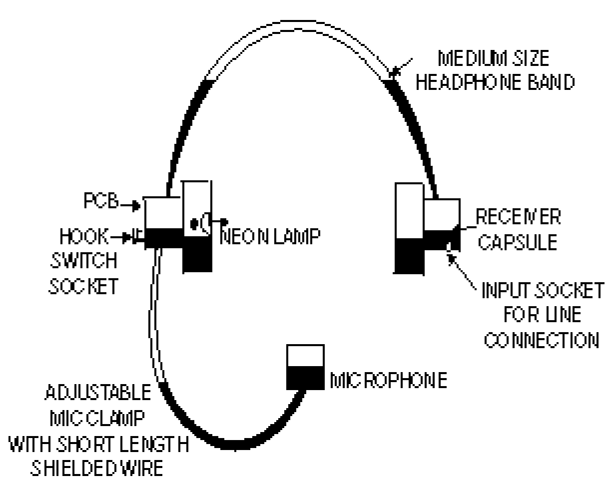
The loudspeaker converts the voice message into the electrical signal which is amplified by transistor T1. This amplified audio signal modulates the carrier frequency generated by transistor T2. The amplitude modulated output is obtained at the collector of transistor T2 and is transmitted by a long wire antenna into space in the form of electromagnetic waves. The transmitted signals can be received

on any short wave receiver without distortion and noise. The range of this transmitter is 25 to 30 metres and can be extended further if the length of the antenna wire is suitably increased along with proper matching.

Telecom Headset





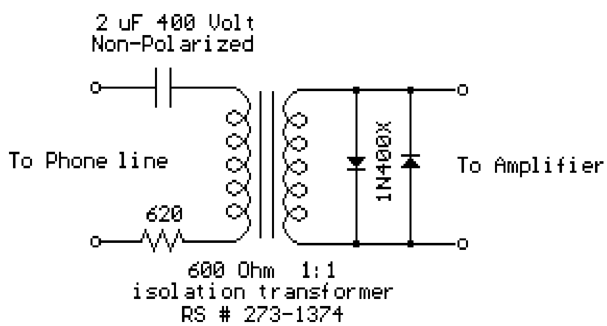


PROPOSED HEADSET

A compact, inexpensive and low component count telecom head- set can be constructed using two readily available transistors and a few other electronic components. This circuit is very useful for hands-free operation of EPABX and pager communication. Since the circuit draws very little current, it is ideal for parallel operation with electronic telephone set. Working of the circuit is simple and straightforward. Resistor R1 and an ordinary neon glow- lamp forms a complete visual ringer circuit. This simple arrangement does not require a DC blocking capacitor because, under idle conditions, the telephone line voltage is insufficient to ionise the neon gas and thus the lamp does not light. Only when the ring signal is being received, it flashes at the ringing rate to indicate an incoming call. The bridge rectifier using diodes D1 through D4 acts as a polarity guard which protects the electronic circuit from any changes in the telephone line polarity. Zener diode D5 at the output of this bridge rectifier is used for additional circuit protection. Section comprising transistor T1, resistors R2, R3 and zener diode D6 forms a constant voltage regulator that provides a low voltage output of about 5 volts. Dial tone and speech signals from exchange are coupled to the receiving sound amplifier stage built around transistors T2 and related parts, i.e. resistors R7, R6 and capacitor C5. Amplified signals from collector of transistor T2 are connected to dynamic receiver RT-200 (used as earpiece) via capacitor C7. A condenser microphone, connected as shown in the circuit, is used as transmitter. Audio signals developed across the microphone are coupled to the base of transistor T1 via capacitor C3. Resistor R4 determines the DC bias required for the microphone. After amplification by transistor T1, the audio signals are coupled to the telephone lines via the diode bridge. The whole circuit can be wired on a very small PCB and housed in a medium size headphone, as shown in the illustration. For better results at low line currents, value of resistor R2 may be reduced after testing.

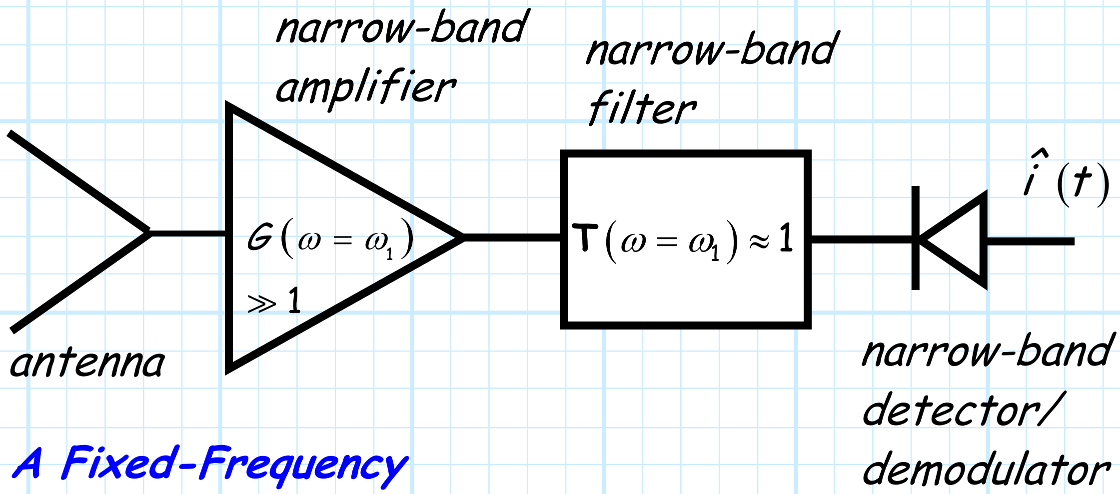
Telephone Audio Interface

These is a circuit that can obtain audio from a telephone line using a transformer and capacitor. To isolate the line from external equipment a non-polarized capacitor is placed in series with the transformer line connection to prevent DC current from flowing in the transformer winding which may prevent the line from returning to the on-hook state. The capacitor should have a voltage rating above the peak ring voltage of 90 volts plus the on-hook voltage of 48 volts, or 138 volts total. This was measured locally and may vary with location, a 400 volt or more rating is recommended. Audio level from the transformer is about 100 millivolts, which can be connected to a high impedance amplifier or tape recorder input. To protect from overvoltage, two diodes are connected across the transformer secondary to limit the audio signal to 700 millivolts peak during the ringing signal. The diodes can be any silicon type (1N400X / 1N4148 / 1N914 or other). The 620 ohm resistor serves to reduce loading of the line if the output is connected to a very low impedance.



The Super-Heterodyne Receiver

Note that the heterodyne receiver would be an excellent design if we **always** wanted to receive a signal at **one** particular signal frequency (ω_1, say):



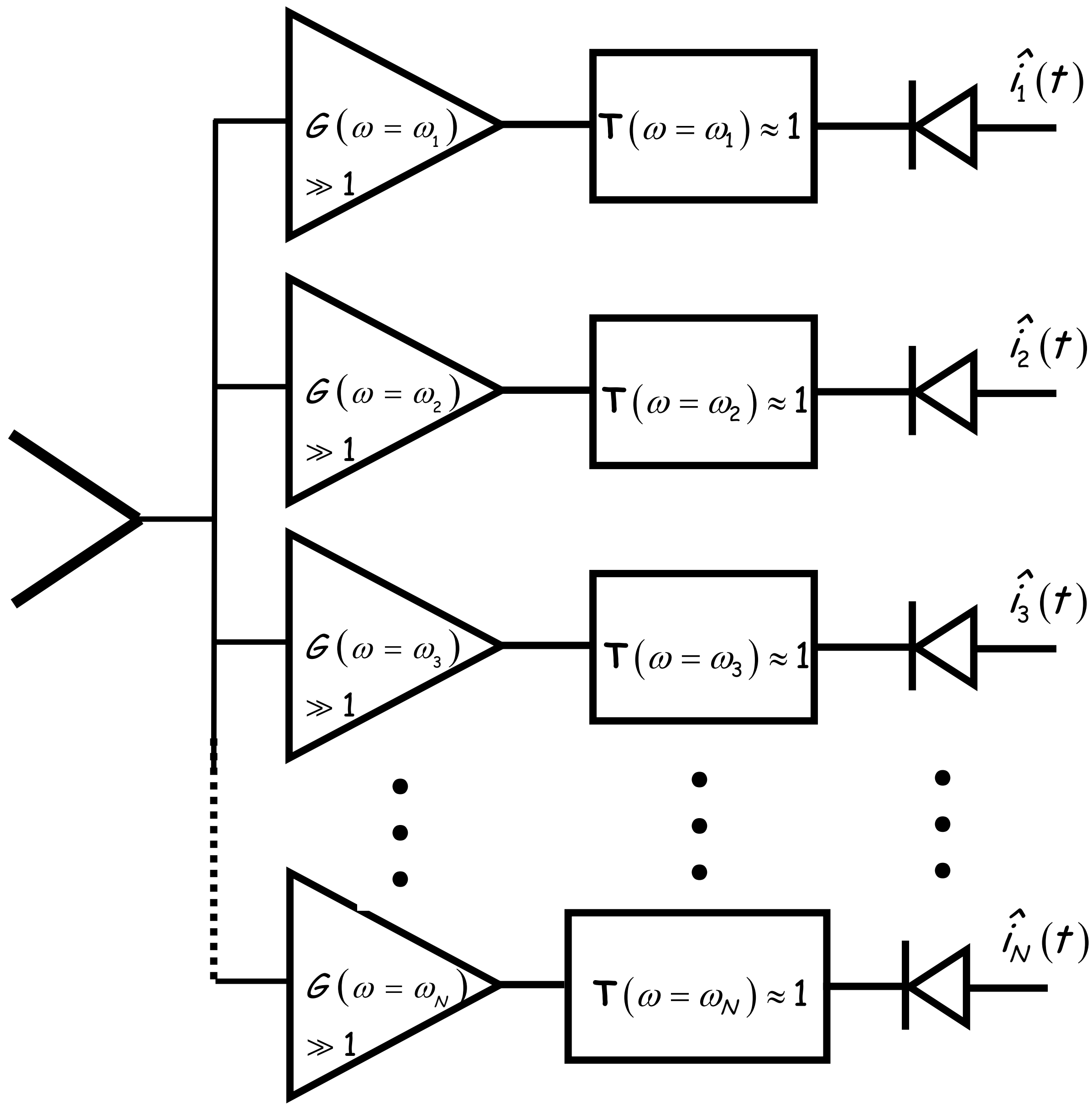
A Fixed-Frequency Heterodyne Receiver

No tuning is required!

Moreover, we can **optimize** the amplifier, filter, and detector performance for **one**—and **only** one—signal frequency (i.e., ω_1).

Q: *Couldn't we just build one of these fixed-frequency heterodyne receivers for **each** and every signal frequency of interest?*

A: Absolutely! And we sometimes (but not often) do. We call these receivers **channelized receivers**.



A Channelized Receiver

But, there are several important **problems** involving channelized receivers.

→ They're big, power hungry, and **expensive**!

For **example**, consider a design for a channelized FM radio. The FM band has a **bandwidth** of 108-88 = 20 MHz, and a channel **spacing** of 200 kHz. Thus we find that the **number** of FM **channels** (i.e., the number of possible FM radio stations) is:

$$\frac{20 \text{ MHz}}{200 \text{ kHz}} = 100 \quad \text{channels !!!}$$

Thus, a channelized **FM radio** would require **100 heterodyne receivers**!

Q: *Yikes! Aren't there **any** good receiver designs!?!*

A: Yes, there **is** a good receiver solution, one developed more than 80 years ago by—**Edwin Howard Armstrong**! In fact, is was such a good solution that it is **still** the **predominant** receiver architecture used today.

Armstrong's approach was both **simple** and **brilliant**:

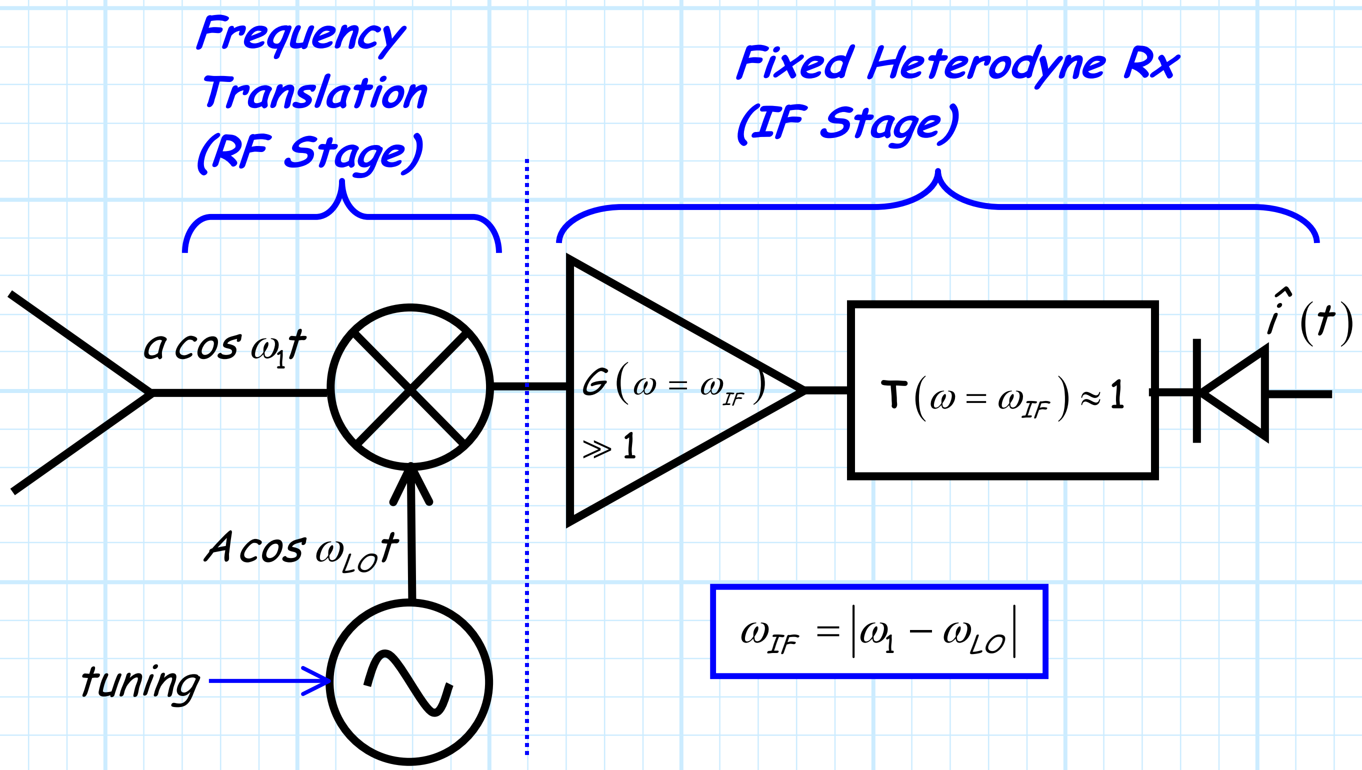
Instead of changing (tuning) the receiver hardware to match the desired signal frequency, we should change the **signal** frequency to match the receiver **hardware**!

Q: *Change the signal **frequency**? How can we possibly do **that**?*

A: We **know** how to do this! We **mix** the signal with a **Local Oscillator**!

We call this design the **Super-Heterodyne Receiver**!

A super-heterodyne receiver can be viewed as simply as a **fixed frequency heterodyne** receiver, proceeded by a **frequency translation** (i.e., down-conversion) stage.



A Simple Super-Het Receiver Design

The **fixed** heterodyne receiver (the one that we match the signal frequency **to**), is known as the **IF stage**. The fixed-frequency ω_{IF} that this heterodyne receiver is designed (and optimized!) for is called the **Intermediate Frequency** (IF).

Q: *So what is the value of this Intermediate Frequency ω_{IF} ?? How does a receiver design engineer choose this value?*

A: **Selecting** the "IF frequency" value is perhaps the most **important** choice that a "super-het" receiver designer will make. It has **many** important ramifications, both in terms of **performance** and **cost**.

* We will discuss most of these ramifications **later**, but right now let's simply point out that the IF should be selected such that the cost and performance of the (IF) **amplifier**, (IF) **filter**, and detector/**demodulator** is **good**.

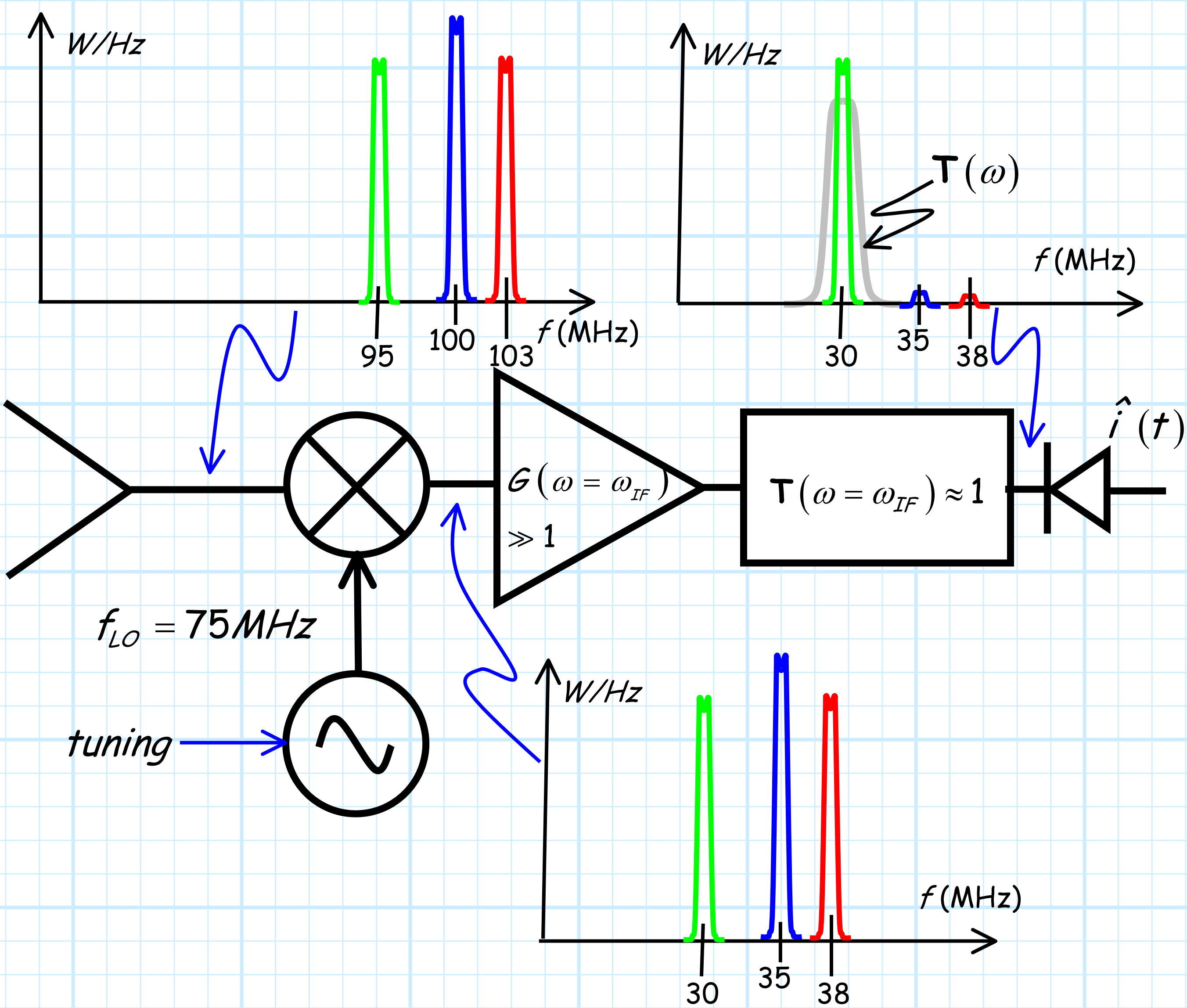
* Generally speaking, as we go **lower** in frequency, the cost of components go **down**, and their performance **increases** (these are both good things!). As a result, the IF frequency is **typically** (but **not** always!) selected such that it is much **less** (e.g., an order of magnitude or more) than the RF signal frequencies we are attempting to demodulate.

* Therefore, we typically use the mixer/LO to **down-convert** the signal frequency from its relatively **high RF** frequency to a relatively **low IF** frequency. We are thus interested in the **second-order** mixer term $|\omega_{RF} - \omega_{LO}|$.

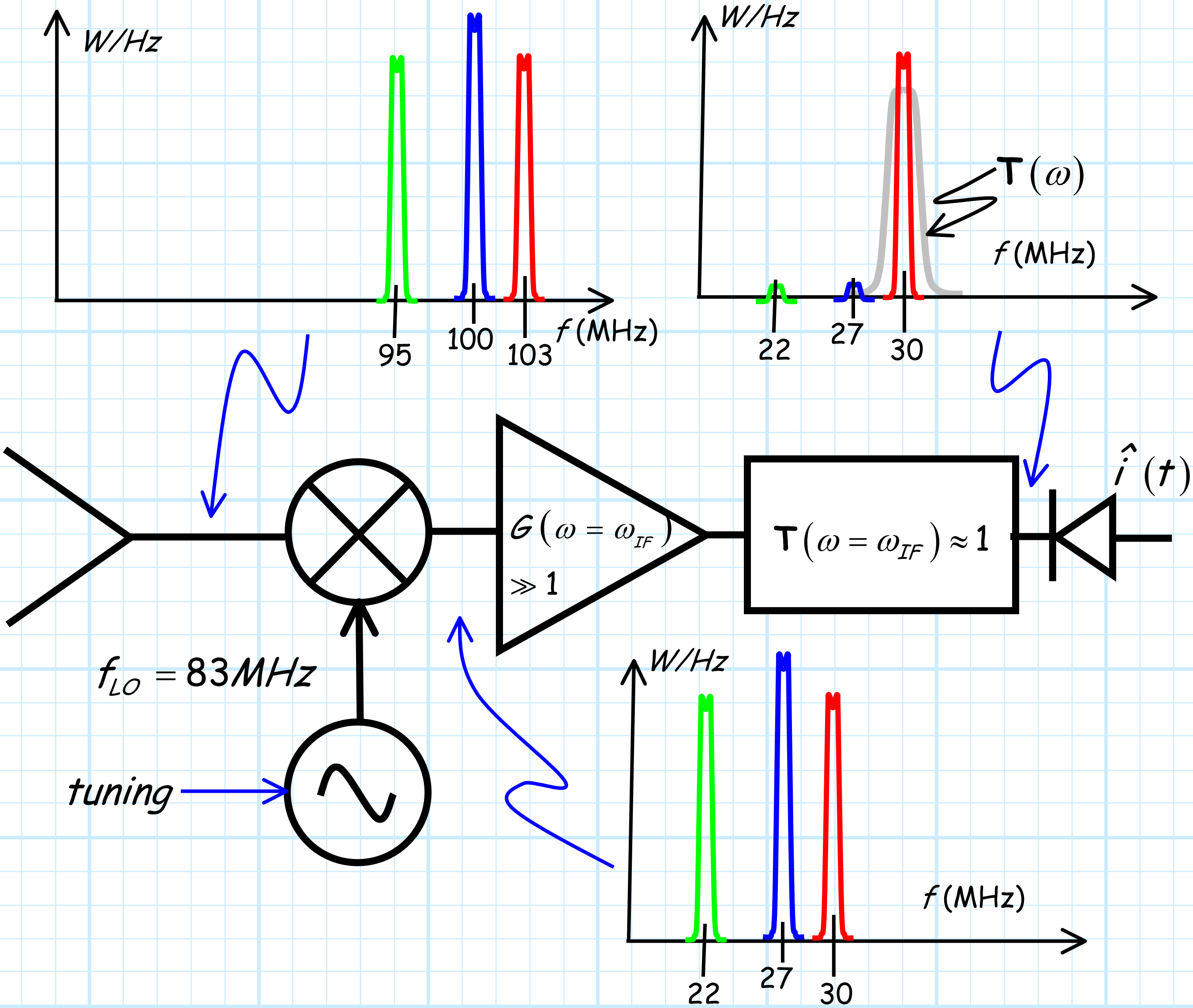
As a result, we must **tune** the LO so that $|\omega_1 - \omega_{LO}| = \omega_{IF}$—that is, if we wish to demodulated the RF signal at frequency ω_1!

For example, say there exits radio signals (i.e., radio stations) at 95 MHz, 100 MHz, and 103 MHz. Likewise, say that the **IF** frequency selected by the receiver design engineer is ***f_{IF}* = 20 MHz**.

We can tune to the station at **95 MHz** by setting the Local Oscillator to 95-20=**75 MHz**:



Or, we could tune to the station at **103 MHz** by tuning the **Local Oscillator** to 103-20=**83 MHz**:



Q: *Wait a second! You mean we need to **tune** an oscillator. How is that any **better** than having to **tune** an amplifier and/or filter?*

A: Tuning the LO is **much** easier than tuning a band-pass filter. For an oscillator, we just need to change a **single** value—its **carrier frequency**! This can typically be done by changing a **single** component value (e.g., a varactor diode).

Contrast that to a **filter**. We must somehow change its center frequency, **without** altering its bandwidth, roll-off, or phase delay. Typically, this requires that **every** reactive element in the filter be altered or changed as we modify the center frequency (remember all those **control knobs**!).

*A 1934 advertisement enticing "men" to enter the **glamorous** and **lucrative** field of radio.*